THE PICTURE OF THE TAOIST GENII PRINTED ON THE COVER of this book is part of a painted temple scroll, recent but traditional, given to Mr Brian Harland in Ssu-Chhuan province (1946). Concerning these four divinities, of respectable rank in the Taoist bureaucracy, the following particulars have been handed down. The title of the first of the four signifies 'Heavenly Prince', that of the other three 'Mysterious Commander'.

At the top, on the left, is Liu *Thien Chün*, Comptroller-General of Crops and Weather. Before his deification (so it was said) he was a rain-making magician and weather forecaster named Liu Chün, born in the Chin dynasty about +340. Among his attributes may be seen the sun and moon, and a measuring-rod or carpenter's square. The two great luminaries imply the making of the calendar, so important for a primarily agricultural society, the efforts, ever renewed, to reconcile celestial periodicities. The carpenter's square is no ordinary tool, but the gnomon for measuring the lengths of the sun's solstitial shadows. The Comptroller-General also carries a bell because in ancient and medieval times there was thought to be a close connection between calendrical calculations and the arithmetical acoustics of bells and pitch-pipes.

At the top, on the right, is Wên *Yüan Shuai*, Intendant of the Spiritual Officials of the Sacred Mountain, Thai Shan. He was taken to be an incarnation of one of the Hour-Presidents (*Chia Shên*), i.e. tutelary deities of the twelve cyclical characters (see Vol. 4, pt 2, p. 440). During his earthly pilgrimage his name was Huan Tzu-Yü and he was a scholar and astronomer in the Later Han (b. +142). He is seen holding an armillary ring.

Below, on the left, is Kou *Yüan Shuai*, Assistant Secretary of State in the Ministry of Thunder. He is therefore a later emanation of a very ancient god, Lei Kung. Before he became deified he was Hsin Hsing, a poor woodcutter, but no doubt an incarnation of the spirit of the constellation Kou-Chhên (the Angular Arranger), part of the group of stars which we know as Ursa Minor. He is equipped with hammer and chisel.

Below, on the right, is Pi *Yüan Shuai*, Commander of the Lightning, with his flashing sword, a deity with distinct alchemical and cosmological interests. According to tradition, in his earthly life he was a countryman whose name was Thien Hua. Together with the colleague on his right, he controlled the Spirits of the Five Directions.

Such is the legendary folklore of common men canonised by popular acclamation. An interesting scroll, of no great artistic merit, destined to decorate a temple wall, to be looked upon by humble people, it symbolises something which this book has to say. Chinese art and literature have been so profuse, Chinese mythological imagery so fertile, that the West has often missed other aspects, perhaps more important, of Chinese civilisation. Here the graduated scale of Liu Chün, at first sight unexpected in this setting, reminds us of the ever-present theme of quantitative measurement in Chinese culture; there were rain-gauges already in the Sung (+12 century) and sliding calipers in the Han (+1st). The armillary ring of Huan Tzu-Yü bears witness that Naburiannu and Hipparchus, al-Naqqās and Tycho, had worthy counterparts in China. The tools of Hsin Hsing symbolise that great empirical tradition which informed the work of Chinese artisans and technicians all through the ages.

Joseph Needham's

SCIENCE AND CIVILISATION IN CHINA

Joseph Needham directly supervised the publication of 17 books in the *Science and Civilisation in China* series, from the first volume, which appeared in 1954, through to Volume 6:3, which was in press at the time of his death in March 1995.

The planning and preparation of further volumes will continue. Responsibility for the commissioning and approval of work for publication in the series is now taken by the Publications Board of the Needham Research Institute in Cambridge, under the chairmanship of Dr Christopher Cullen, who acts as general editor of the series.

SCIENCE AND CIVILISATION IN CHINA

. . . people naturally don't like the dark. Who would want to be a miner digging galleries in the vicinity of the yellow springs?

WANG CHHUNG *Lun Heng* c. +82

China is also a land of mines.

L. CARRINGTON GOODRICH
In Nigel Cameron (ed.), *The Face of China*

On one occasion, while traveling across the province of Shansi, the writer passed several strings of mules, each animal carrying large slabs of coal. Upon inquiry, the source of the coal was found to be about a day's journey distant. On visiting the mine, no buildings, other than a few sheds, were to be seen. The shaft was a mere well with a crude windlass, unlined and without a ladder, except as there were occasional toe holds in the rock. Half a dozen men were sitting around the shaft, and after some conversation, permission was laughingly granted to visit the workings. A rope was tied around my waist, and I was lowered by hand until I landed in the mud 60 feet below. From this point a low tunnel led 200 feet to the mine face. There was no timbering in the tunnel, and the height was so low that one could just crawl on hands and knees. At the end of the tunnel, two seams of coal were exposed, each some ten inches thick and separated by about the same thickness of shale. Here were a dozen miners, each armed with a short stick, at the end of which was an iron pick. Lying on their sides, these men undercut the seams of coal and wedged off large blocks. These slabs were then put on a wicker basket, dragged back to the shaft by a small boy, and hoisted to the surface by the same rope which served the workers. The mine was quite wet, and as water accumulated, it was raised in leather buckets.

GEORGE B. CRESSEY *Land of the 500 Million*

李約瑟著

中國科學技術史

冀朝鼎

JOSEPH NEEDHAM

SCIENCE AND CIVILISATION IN CHINA

VOLUME 5

CHEMISTRY AND CHEMICAL TECHNOLOGY

PART XIII: MINING

BY

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UNIVERSITY OF DENVER

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge CB2 1RP, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, United Kingdom
40 West 20th Street, New York, NY 10011–4211, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1999

Printed in the United Kingdom at the University Press, Cambridge

Typeset in Baskerville MT 11.25/13pt, in QuarkXPress™, GC

A catalogue record for this book is available from the British Library

ISBN 0 521 58000 5 hardback

This book is respectfully dedicated to

CHANG HUNG-CHAO

China's first professor of geology
whose two works, *Shih-Ya* and *Ku Khuang Lu*,
opened the way to the serious study
of the history of mining in China

HERBERT CLARK AND LOU HENRY HOOVER

whose annotated translation of Agricola's *De Re Metallica*
did justice to one of the great figures of the Renaissance
and has properly become a classic in its own right

ARNOLD SIEGERS

greatly missed friend and fitting representative here
of those many mining men who share a deep interest
in the history of their profession

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF MAPS

LIST OF TABLES

LIST OF ABBREVIATIONS

The following abbreviations are used in the text and footnotes. For abbreviations used for journals and similar publications in the bibliographies, see pp. 438ff.

CYTC	*Chien-yen I-Lai Chhao-Yeh Tsa Chi*
CYYL	*Chien-yen I-Lai Hsi-Nien Yao-Lu*
HCP	*Hsu Tzu-Chih Thung Chien Chhang-Pien*
HWHTK	*Hsu Wen Hsien Thung Khao*
KT	*Kuan Tzu*
LWTT	*Ling Wai Tai Ta*
MCPT	*Meng Chhi Pi Than*
PTKM	*Pen Tshao Kang Mu*
SHC	*Shan Hai Ching*
SHY:CK	*Sung Hui Yao Chi Kao: Chih-Kuan*
SHY:HF	*Sung Hui Yao Chi Kao: Hsing-Fa*
SHY:SH	*Sung Hui Yao Chi Kao: Shih-Huo*
TKKW	*Thien Kung Khai Wu*
TNKC	*Tien-nan Khuang-Chhang Thu Lueh* (Wu Chhi-chün (*1845*))
TSFYCY	*Tu Shih Fang Yü Chi Yao*
TT	*Tao Tsang* (Numbers of the individual works from Wieger (1911).)
WHTK	*Wen Hsien Thung Khao*

AUTHOR'S NOTE

All I can offer to diminish the severity of criticism, is freely to admit there is much room for it.
Thomas Ewbank[1]

When Joseph Needham in the summer of 1979 first raised the possibility that I write the section on mining for *Science and Civilisation in China*, it was not because of any work that I had previously published on the history of technology in China – there was none. Rather, I think he hoped that my as yet publicly unrevealed interest in Chinese technology, together with previous research on the society and economy of traditional China, would lead me to examine the development of China's mining technology broadly rather than narrowly, placing it in the larger context of Chinese society as a whole. That is certainly part of what I have tried to do in this study.

At the same time, I subscribe to the idea that good history of technology must begin with a careful examination of the technology itself. This is all the more important when dealing with a technology that has previously been largely neglected, certainly the case for mining in China. It was precisely here, however, that I began woefully unprepared. The sole intrusion of science into my formal education in high school and beyond was a one-year high school course in physics. Six years of Latin and three years of ancient Greek could hardly compensate for this gap, at least not for the purposes of this study. Thus, I was forced to learn as I went along the geology, petrology, mineralogy, chemistry and metallurgy without which one cannot fully comprehend mining processes. Acquiring the necessary related knowledge turned out to be much more daunting than I had anticipated. Despite my best efforts, my command of these fields still suffers from the *lacunae* that all too often afflict the knowledge of the autodidact. Insofar as possible, I have tried to avoid misunderstandings by consulting experts in various areas of mining and mining history. Among those to whom I owe a very special debt of gratitude are Robert C. Armstrong (Denver), Noel Barnard (Canberra), Paul Craddock (London), T. Ko (Peking), Willem Lodder (Denver), Lung Tshun-ni (Taiwan), and Donald B. Wagner (Copenhagen). I also wish to thank Otis E. Young, Jr (Tempe) and William C. Stickler (Denver). All were very generous in sharing their knowledge of mining history, their technical expertise, and, in some cases, even their editorial acumen. Though I am certain that I have not succeeded in removing all technical misunderstandings or terminological slips, without their help I would certainly have stumbled far more often.

Special thanks must go to Graham Hollister-Short (London) and Hans Ulrich Vogel (Tübingen) who served as Cambridge University Press readers for an earlier draft. Their detailed and erudite comments were enormously helpful. Indeed, this

[1] Ewbank (1842), p. iv.

would be a better book if constraints of energy and time had not forced me to forego following up many of their thoughtful suggestions. As it was, Hans Ulrich Vogel went far beyond serving as a reader, providing many materials that helped me introduce more extensive comparison with other mining traditions, and also serving as an unfailing source of encouragement especially in the later stages of my work.

In organising and writing this volume, I have aimed to make the final product 'reader-friendly'. I have tried to keep in mind at least three kinds of readers who will bring to this book widely varying backgrounds and who often will be looking for quite different kinds of information: (1) those who have no special expertise in the history of science and technology but have an interest in China and would like to know something about what was after all a very important activity in traditional China; (2) those who have a special interest in the history of technology and science in China; and (3) those who study the history of mining or the history of technology in other cultures and wish to turn to this book as a comparative reference. What follows then is something of a roadmap intended to help these different kinds of readers to ferret out those discussions most likely to meet their particular interests.

Readers with broader interests relating either to China or to comparative historiography will probably want to pay special attention to the introduction (*a*), the overview of the scope of mining in China (*b*), the discussion of the products of Chinese mining (*e*) and the closing sections on labour and capital in Chinese mining (*k*) and the rôle of the government (*l*).

The main purpose of the introduction is to describe certain characteristics typical of all premodern mining and to suggest how they made mining a unique technology very different in crucial ways from other, better studied and better understood technologies such as farming and clothmaking. Examples are included to illustrate how these characteristics revealed themselves in traditional Chinese mining.

The overview of the scope of mining in China then looks mainly at the variety of mining production in China as well as attempting to present a snapshot of that part of the Chinese population that was engaged in mining.

The section on the products of Chinese mining was not a part of my original plan. I had at first intended to include a brief but fairly comprehensive outline of the history of Chinese mining, focusing on major advances in Chinese mining technology but also discussing other developments that had a significant impact on the mining industry. I abandoned that idea as it became clear that the great variety and complexity of the topics deserving inclusion threatened to lead me into a long and unwieldy account which in any case would have contained considerable material necessarily repeated in other parts of the study.

Alternatively, and in the interest of brevity, I could have limited myself to little more than a concise summary of major developments. But that threatened to become a largely meaningless and perhaps unreadable catalogue, not much more useful than most of those tabular chronologies found in the prefatory or closing pages of history textbooks. In the interests of manageability and coherence, then, I have incorporated historical overviews into a series of discussions of the various

products of Chinese mining, giving a relatively brief history of their mining and use in traditional China. I hope these will be especially of use to readers whose main interest may be the rôle played by a given mineral in traditional China.[2]

A major theme of this study is that, perhaps more than in most other technologies, the technological options adopted in Chinese mining often had little to do with narrowly technological considerations but a great deal to do with related concerns such as the availability of capital, the worldview of the miners, the rôle of the government. We close therefore with explicit examination of the most important of these 'external' influences. In considering the rôle of the labour force, we look at the way mining labour was organised as well as how the values and 'religious' beliefs of the miners impacted on mining practice. Regarding capital, we examine the perennial dearth of capital in Chinese mining, why that was the case, and the effects it had on technological advance in mining. Finally, we consider also the very mixed attitudes of Chinese emperors and government officials toward mining, the policies that emerged from those perspectives and the thorny question of the actual effects of those policies on the development of Chinese mining.

Those readers seeking especially an understanding of the Chinese traditional mining technology *per se* might begin with the discussion of China's ore deposits (*d*). I have tried to make this section comprehensible for readers unfamiliar with geology and the other sciences related to mining. The section opens with a concise outline of the different kinds of ore deposits and how they affected traditional mining practices. This is followed by a general description of China's ore deposits, stressing those characteristics (irregularity, limited extent) that did much to define the parameters of Chinese mining. Finally, there is a summary of China's ore deposits by region. (More details on ore deposits can also be found in the section (*e*) dealing with the products of Chinese mining.)

The five sections (*f*) through (*j*) form the technological core of this study. The section on prospecting and exploration, after noting the often underestimated importance of the accidental discovery of minerals and industrial materials, discusses what if any influence general Chinese ideas on the formation of minerals may have had on the understanding of prospecting. It then explores the question of how prospectors actually went about their work, including the large repertoire of methods they used to identify what they found.

We then turn to placer and and other kinds of surface mining, those earliest mining techniques that developed in imperceptible steps from the simple grubbing for the suitable rocks on which mankind had come to depend (along with wood and bone) before metals came into use. Placering is basically a simple technique

[2] While it has been convenient in many of these volumes to carry the discussion down to about the beginning of the Chhing (cf. Vol. 1, pp. 148–9), that was not a workable principle in this case, given the persistence of traditional mining practices into our own century and even today. Our cutoff, then, has had to be not chronological but topical. Even quite recent evidence has been drawn upon when it related to techniques that have clearly long been in use. I shall often refer to these techniques as 'traditional' or 'premodern', using those words in a general way simply to indicate mining before the extensive introduction of explosives and steam or electric power (cf. Bromehead (1956), p. 1).

requiring at a minimum only a digging or shovelling implement, a washing utensil and a great deal of labour. Over time, improved methods were devised such as the use of sluice boxes and rockers, but placering frequently remained right into the present century a last resort for many of China's poorest who had no land or capital resources and who therefore turned to placering to eke out the few cash that might keep them alive from day to day.

Technologically, it is underground mining that poses the great challenges to miners, challenges that in a general way increase as mining operations grow in scope and proceed deeper underground. It is here that we shall examine how Chinese miners dealt with the recalcitrant country rock that so often encloses ore deposits, making extensive use of firesetting but little use of gunpowder. We shall see the early emergence of sophisticated methods of supporting roofs and walls which otherwise threatened to collapse and bury both miners and workings. We shall see how the Chinese coped with the task of removing materials (ore or waste) from the mine, second only to breaking rock in the amount of dogged physical energy required. Closely related to this task was the need also to deal with what was frequently the miner's greatest enemy: water. Inability to handle mine waters forced the abandonment of many a mine in the traditional period. More briefly, we shall also consider how Chinese miners coped with the problems of providing working light in what otherwise would be the total blackness of the mine and, by means of various ventilation techniques, sufficient air for breathing.

The success of metal mining was often crucially dependent on the ability to process mined ore for use in the smelter. Basically, the goal was to produce either a powder 'concentrate' with enough metal content to make the smelting economical or pieces of ore of a consistent size that would make smelting possible. These techniques ranged from very simple processes, essentially the same as those used in placers, to larger operations that were not significantly more complex in theory but which were sometimes surprisingly elaborate in practice.

In closing our discussion of the specifically technological side of mining, we note that the line between mining and metallurgy can, in some cases, be very fine. In general, I have been content to avoid discussion of metallurgy, which will be dealt with in other volumes in this series on ferrous and non-ferrous metallurgy. Only when certain aspects of metallurgy needed to be understood for our discussion of mining practices (e.g. the use of cupellation and amalgamation in gold and silver mining), do they receive some treatment here. The main exception is one of the greatest achievements of the Chinese mining tradition, the first use on an industrial scale of the 'wet copper' or 'copper cementation' process by which the Chinese were able to precipitate copper from mine waters onto iron, thus creating the world's first use of hydrometallurgy. This is a case where a metallurgical reaction is the basis of a mining practice, and it is deservedly discussed in a section (*j*) of its own.

The conclusion draws on what has gone before to attempt an explanation of why, after very promising beginnings, Chinese mining technology seems in large measure to have stagnated in later periods. We return to our main theme that it was

primarily conditions extraneous to mining technology itself that caused so much of Chinese mining to remain at a relatively primitive level.

A particularly vexing problem for the historian of mining technology in China concerns the search for written sources, especially on the technology itself. Mining, unlike agriculture[3] or salt production, did not give rise to a voluminous body of writings in China. Happily, more than I could have anticipated when I began, that lack has been compensated for in recent years by some remarkable archaeological excavations. Hence, a discussion of what archaeology has contributed to our knowledge especially of traditional mining takes pride of place at the beginning of our discussion of sources in Section (*c*). This is followed by a consideration of what is available in the way of written sources, looking in some detail at not only the kinds of practical information they contain but also their general perspective on topics that we would see as falling in the domain of geology, mineralogy and the like.

Research for this study has often been hindered by the absence of a really good Sinological library in the Denver region. The ever helpful staff of the interlibrary loan department of Penrose Library at the University of Denver and visits to major Sinological libraries have given me access to much but not all of what was not available at home. As a result, I have not in every case been able, for example, to check quotations from primary sources against the originals, though I have tried to do so wherever possible. Certainly, where I had any doubt about the accuracy of a citation by a modern author, and especially where the exact meaning was puzzling or crucial, I made every effort to track down the original, sometimes in more than one edition. In other cases, I have sometimes made do with other authors' citations. I have also tried consistently to distinguish those primary materials discovered through my own digging in the primary sources from those to which I was led by the researches of others. In the first case, I give the original reference and exclude references to secondary sources citing the passage unless they contained a translation or useful commentary. In the second case, the secondary sources are always cited, with or without citation of the original.

In addition to those persons mentioned above, I would like to express special thanks to the following who read and commented on drafts of the various sections or offered help in other ways:

Emma C. Bunker (Denver)
Chen Yanfu (Gejiu)
Chen Lufan (Kunming)
Hu Chuyan (Guilin)
Lew Hyer (Denver)
David N. Keightley (Berkeley)
Richard H. Kimball (Denver)
Kinugawa Tsuyoshi (Kyoto)
Lily Kecskes (Washington, DC)
Noel Kirschenbaum (San Francisco)
Sharon LaPierre (Boulder)
Li Liangcai (Gejiu)
Li Youchun (Gejiu)
Li Zhongjun (Peking)
Lin Chaomin (Kunming)
Lu Benshan (Huangshi)

[3] Vol. 6, pt. 2, p. xxiv.

Robert Maddin (Cambridge, Mass.)
Mei Jianjun (Peking)
Homer E. Milford (Santa Fe)
Nathan Sivin (Philadelphia)
Jenny So (Washington, DC)
Harry Tu (Denver)
Tian Changhu (Chengdu)
Wang Chunzeng (Guilin)
Wang Hsi (New York)
Yang Baocheng (Wuhan)
Yeh Nai-chhing (Guilin)
Yin Weizhang (Peking)
Zhu Shoukang (Peking)

There are also three institutions to which I am specially indebted. The East Asian History of Science Trust financed several research stays in Cambridge. The first one, for six months at the old East Asian History of Science Library (I still recall fondly my spacious and sunny third floor working area), enabled me to get my research off to a running start. Then, after a number of years during which research and writing proceeded at a much slower pace, and sometimes even had to be put aside, I was able to return for several stays at yearly intervals to the splendid, recently completed Needham Research Institute, which I found to be an ideal working environment.

Twice during my research, the Deutsches Museum in Munich provided me with the opportunity to make use of its superb library on the history of technology. I was thus able to become more familiar especially with the impressive body of work on the history of mining compiled in recent decades by German-speaking scholars. They are clearly at the forefront of research into the history of mining and their work deserves to be better known in the rest of the scholarly world.

It is also a pleasure to be able to thank my home base, the University of Denver, which has been very generous with various periods of release time and other kinds of support without which this volume might still be awaiting completion. Another kind of support, indispensable, came from Carol Taylor and her colleagues in the Faculty Computing Lab. More than once, I came away amazed and relieved, thanks to their ability to take on and defeat the challenges of quirky software. And David Song, a graduate student in the Economics Department, provided a great deal of valuable help in organising the data for production of several maps.

Finally, my deepest gratitude is reserved for the two people without whose support this book simply would not have been written. The first is the late Joseph Needham. His never-flagging faith in what I would finally produce helped me, after a considerable hiatus, to return in a serious way to this project and bring it to completion. Though I regret he is not able to see the final project, I take some consolation that he read and was pleased with an earlier draft.

For day-to-day support during these many years, I have always been able to depend on my wife, Jutta. The most loving and generous person I have ever known, she somehow has been able to meet all the demands of her career as a successful artist without ever being less than a deeply caring wife and mother. Her I thank most of all.

36a. MINING

(a) INTRODUCTION

. . . the subject of mining is a very extensive one, and one very difficult to explain . . .

Agricola[1]

Whether in times past or more recently, few aspects of the history of technology have been so poorly understood as mining. When writing the preface to their classic translation of Agricola's +1556 *De Re Metallica*, Herbert and Lou Henry Hoover declared themselves 'appalled at the flood of mis-information with regard to ancient arts and sciences [especially mining and metallurgy] which has been let loose upon the world by the hands of non-technical translators and commentators.'[2]

Modern students of traditional China have generally finessed the complexities of mining by avoiding discussion of the technology itself even when they recognised the importance of the industry.[3] Their reticence has been fostered by the Chinese sources themselves. These were, for the most part, the product of officials who may have discussed from time to time one or another aspect of mining as it affected government revenues or the welfare of the people, but who ordinarily knew little about actual mining practice and had little interest to learn more.[4]

The reticence of the sources belies the great importance of mining and metallurgy in China even from very early times. To be sure, China was not among the earliest civilisations to use metals. Nevertheless, in the −2nd and −1st millennia, she became 'one of the most advanced metallurgical cultures of the ancient world and, indeed, the most prolific of all in terms of sheer quantity of manufacture and variety in artefact design.'[5] In terms of the value of its product, mining was at least by Thang and Sung times (+7th to +13th centuries) the second most important economic activity in China, after agriculture. In addition to its four main products – coal, iron, copper and gold, the Chinese mined well over fifty other mineral products (Table 1). In terms of the numbers of people involved, mining was the third largest productive

[1] Hoover & Hoover (1912), p. xxv. [2] Hoover & Hoover (1912), p. iv.

[3] One notable exception is E-tu Zen Sun. Especially in her discussion of copper mining in Yunnan (Sun 1964) and of mining labour in the Chhing period (Sun 1967), she has a good deal to say about mining technology.

[4] Thus, Robert Hartwell could very effectively exploit Sung sources to develop a powerful interpretation of the importance of iron and steel in the Northern Sung economy (Hartwell (1962), (1963), (1966), (1967)) but was often precluded by the silence of those same sources from dealing in any depth with important aspects of the organisation and technology of iron and steel production. He sought for clues in the mining practices in late medieval and early modern Europe as well as in 19th and 20th century China (Hartwell (1962), p. 161; (1966), pp. 41ff.) though it is very much open to question how far Chinese mining during the Sung resembled especially the European practices. Certainly, one cannot say for the Sung what Hartwell's major source for European practices, John U. Nef, says about medieval mining in Europe, that the miners' associations 'worked many concessions as a single undertaking much as peasants ploughed and sowed their holdings in common.' (Nef (1952), p. 473.) That was certainly not the case for most Sung agriculture and probably not for Sung mining either.

[5] Barnard (1983), p. 269.

Table 1. *Estimated distribution of mining labour in China (early 20th century)*

Mineral Product	Number of mine workers	Percentage
Coal	600,000	26.2
Iron	100,000	4.4
Tin and wolfram (tungsten)	50,800	2.2
Gold	23,800	1.0
Antimony	14,000	0.6
Manganese	5,000	0.2
Zinc	4,850	0.2
Lead	2,500	0.1
Copper	2,400	0.1
Arsenic	2,000	0.1
Mercury	1,500	0.1
Bismuth	500	—
Cobalt salts	500	—
Silver	200	—
Molybdenum	100	—
Salt	560,980	24.9
Kaolin and pottery clay	435,000	19.0
Bricks and tiles	220,000	9.6
Quarries, stone, grave and sand	156,000	6.8
Cement	31,000	1.4
Gypsum	13,400	0.5
Natural soda	13,070	0.5
Magnesite	10,750	0.5
Talc	10,300	0.5
Abrasives	8,300	0.4
Alunite	8,000	0.4
Native saltpetre	3,000	0.1
Phosphate	2,740	0.1
Soapstone	1,500	0.1
Mica	1,000	—
Ochres	1,000	—
Fluorspar	900	—
Petroleum	500	—
Rock crystal	500	—
Feldspar	500	—
Calcite	500	—
Sulphur	470	—
Asbestos	340	—
Pyrite	300	—
Graphite	300	—
Precious stones	300	—
Baryte	200	—
TOTAL	2,289,000	100.0

Based on Torgasheff (1930a), p. 782, Table 44, with percentages calculated by the author. (That the percentage figures, despite omitted workers, total 100 is simply an accident of rounding.)

activity, after agriculture and clothmaking.[6] If we are to comprehend China's traditional society and economy, we can hardly afford to neglect a technology that affected the lives of so many of the Chinese people. The understanding of mining technology, in turn, begins with the recognition that mining in the premodern context, whether in China or elsewhere, displays certain characteristics that distinguish it from other premodern technologies.

(1) GEOLOGICAL AND GEOGRAPHICAL CONSTRAINTS ON MINING

In comparison with other technologies, mining is something of a 'technology apart', in at least two senses. First, there are what we might call the spacial constraints on mining. Much of mining is undertaken in relatively isolated places that are hard to get to. Second, mining technology itself displays certain characteristics that differentiate it from other technologies. Most of this introduction will deal with these latter characteristics. But first we must take a moment to look at locational constraints that serve as the ultimate arbiter of where mining will take place.

To a much greater extent than other industries, the success of mining operations depends on geology and geography. Nature determines *without appeal* where successful mining can occur. Economically exploitable ores are not abundant. Chinese miners in Yunnan had the proverb: 'For every mountain with a workable deposit (*khuang* 礦), a thousand mountains have only veinlets (*yin* 引).'[7] While mineral deposits are actually very widespread, ore deposits – those deposits where the mineral or other desired material is concentrated sufficiently to be economically workable – are generally rare. Since metal deposits in particular often occur in rugged, isolated terrain, providing provisions and supplies for the miners can be a major concern and cost of mining operations.

Indeed, mining entrepreneurs often faced here a classic 'Catch 22' situation. The weight and bulk of the ore usually precluded shipping it any great distance for processing. On the other hand, if the materials required to carry out the processing, especially fuel, were not available near the mines, the costs of premodern transportation could effectively preclude bringing them in. The result was that many potentially rich deposits, even when known, were never worked in traditional times.[8] By contrast, it was precisely the fortuitous availability of large deposits of iron ore occurring close to extensive deposits of coal that made possible the flourishing iron industry of north China.[9]

[6] For figures on the numbers of people involved in mining and directly related activities, cf. (*b*) below. The +17th century *Thien Kung Khai Wu* (*TKKW*), the most detailed and comprehensive pre-20th century discussion of the range of technologies used in traditional China, devotes about one-fourth of its length to mining and related technologies; Yabu'uchi (*1969*), p. 365.

[7] Yen Chung-phing (*1957*), p. 51.

[8] This was perhaps especially true for iron deposits; Read (1912), p. 25.

[9] Jameson (1898), pp. 366, 367. In the same way, China's production of sulphur, nearly all of which came from iron pyrites, depended on the presence of near-by deposits of coal as fuel for the dry distillation process (*kan-liu* 干餾) used to extract the sulphur; Chang Yun-ming (*1982*), p. 32.

The geological constraints that limited where mining could be carried on also had a very direct impact on the kind of technology that could be used. As we shall have cause to remark more than once, mining was a technology that required above all the expenditure of great amounts of force. In traditional times, it was mainly waterpower that had the potential to replace human and animal energy. But, as George Basalla has noted, mining was much less able than other industries to accommodate itself to the possibilities of waterpower.[10] One did not have the option of siting one's mine next to a watercourse. And bringing the water to the mine by means of canals, flumes and the like was usually costly and difficult.[11]

Geographical realities also limited mining markets to an extent that was not true of other industries. Even after processing, the products of mining still tend to be heavy and bulky. Since the mines were typically distant from the markets for their production, economical transportation was an important condition for their viability. Even mines that had begun successfully to serve a certain market might find their further growth restricted because high costs of transport precluded their access to larger markets.

(2) The Special Characteristics of Mining Technology

Besides the spacial constraints to which it is subject, mining technology itself also displays at least four major characteristics that distinguish it from other technologies, in China as elsewhere:

(1) Mining is arguably the most unpredictable of all productive activities, and therefore highly risky for those who engage in it.
(2) Mining is a uniquely *ad hoc* technology, frequently requiring modification of its techniques according to the nature of the deposits encountered.
(3) Mining is an especially difficult technology in terms of the physical and social demands it makes on those engaged in it.
(4) The mining practices in use at any given time in one country or even one region can vary significantly in scope and sophistication, depending not only on natural conditions and the kinds of techniques potentially available but also on a host of political, social and economic conditions.

(i) *The high risk of mining*

It is in the nature of ore deposits that one never knows how long a given deposit will continue to repay working. What is certain is that mining intrinsically is a wasting activity: all deposits that are worked steadily eventually cease to pay, at which

[10] Basalla (1988), p. 149.
[11] And, of course, the very nature of most traditional mining, with its cramped and winding excavations, largely precluded any use of water-powered machinery.

point the mine has to close and the miners must find work elsewhere.[12] A Yunnan gazetteer colourfully describes what could happen to a thriving mining town when the deposits failed:

One day there are carriages and crowds in the streets, lights shine from ten thousand houses; in a flash it all reverts back into a wilderness, where birds build their nests and wild beasts have their lairs, and nothing is visible but nettles covering ruins in the valley. Only woodcutters or herdboys will occasionally come here, to pick up some leftover pieces of ore from the former mine.[13]

The unpredictability of deposits increases where the deposits are relatively small and irregular, as was more often than not the case in China.[14] In those conditions, the search for workable deposits is itself more risky, while those deposits that are found stand a greater chance of being short-lived. In contrast to agriculture, where the farmer more often faces the threat of reduced harvests rather than no harvest at all and where good years can be expected to follow bad years, mining is much less forgiving: a great deal of effort can easily result in no return at all. Moreover, farmers can minimise their risks by means of scattered plots, varied crops, intercropping and the like.[15] By contrast, mining in traditional societies offered few options for coping with risk. About the best strategy for part-time peasant miners was to look on a mine as potentially the source of a continuing, modest revenue stream that one should attempt to prolong indefinitely with small-scale mining techniques, rather than as a resource to be intensively exploited to obtain maximum return in the short term at the risk of rapid exhaustion of the deposit.[16] This was all the more true because a further characteristic of at least underground mining is that it tends to become technologically and economically more difficult as it proceeds; all the problems of mining, including water management, ventilation and the overall safety of the excavation and of the miners, typically are harder to deal with at greater depths.

If such small-scale mining was hardly likely to draw on advanced, costly technology, larger, deeper mines presented yet another problem: irregular deposits combined with relatively primitive understanding of the geology of ore deposits to make it virtually impossible to estimate with any precision what it was going to cost to open a mine and bring it to profitable exploitation.[17] We shall see (Section (*k*)(5)) that

[12] As Donald Wagner has pointed out to me, bog iron, which actually does grow in the ground, is an exception to this generalisation, if a rather minor one.

[13] *Yun-nan Thung Chih* ch. 73, translated in Sun (1967), p. 67. This text also reflects the fact that even substantial mining towns and cities often grow up as classic 'one-industry towns' that have no means of survival after the deposits give out and the mining ceases. For the growth of Tung-chhuan 東川, the major copper production centre in Yunnan during the Chhing, see Satoi (*1972*), p. 28.

[14] Slessor (1927), p. 52. China not only has relatively few large mineral deposits but even these tend to consist of ores of minerals (e.g., tungsten, antimony, rare earths) that were of no interest to Chinese in traditional times; Li Yü-wei *et al.* (*1993*), p. 37.

[15] Godoy (1990), p. 10.

[16] Brelich (1904), p. 495 (comments by G. T. Holloway). The proverbial expression of this attitude was *hsi shui chhang liu* 細水長流, literally, 'A small stream flows without interruption', i.e., economising on the use of a resource will preserve it for a long time; Bueler (1972), p. 45, no. 114.

[17] Thang Ming-sui *et al.* (*1958*), p. 45.

Map 1. Mining regions and sites mentioned in the text (excluding those in China and Europe).

entrepreneurs typically responded to this high level of risk with a variety of strategies that virtually assured that most larger Chinese mines would be sadly undercapitalised and thus limited in their ability to make any technological improvements that entailed significant costs.

The great unpredictability of mining itself, as well as the frequently inauspicious economic, political and social conditions that were well beyond the control of the miners, could also encourage what we might regard, but probably wrongly, as an irresponsible attitude toward mining. Rather than risking the large capital and labour expenditures required for the systematic exploitation of ore deposits, miners and mining entrepreneurs frequently chose a 'hit-and-run' approach: extract what could be obtained with maximum ease and minimal investment, and then move on. Given the poor quality of so many of the ore deposits available to traditional miners, this strategy can equally well be viewed as 'rational'. As Lin Ken Wong noted in his superb study of the tin mining in Malaya (Map 1) which was largely carried on by Chinese miners, 'the economy of any technique of mining and organization was ultimately dependent on the richness of the [ore deposit]'.[18] Rational or not, we have here another reason for the primitive practices of so much of premodern mining.

(ii) *The uniquely* ad hoc *character of premodern mining*

It is a truism among miners that every mine is to some degree unique.[19] Often enough, even deposits that occur in broadly similar conditions in the same area have little in common. As a result, the rewards of premodern mining often bore little relation either to technical ability or to labour expended.[20] Miners understood this problem very well, and in trying to cope with it placed their reliance on a whole range of supplementary 'tools' including luck, dreams, talismans, and superstitions of every kind.

Especially in the earlier stages of mining, the extreme variety of the environments in which ore deposits are found as well as the nature of the deposits themselves made it particularly difficult for miners to develop a sound body of knowledge that cumulatively built upon past experience. Knowledge gained in one mining district was all too easily lost as that district's mines were worked out and the miners moved on to mines in other areas, with different characteristics. There must also have been many cases where experience gained in one area was inappropriately applied to another area's very different deposits, with consequent waste of time and effort and capital. In addition, whatever the state or effectiveness at any given moment of a portable, 'professional' body of knowledge that full-time miners carried with them from mine to mine, there was also a great deal of experience and knowledge limited to particular areas where mining was carried on exclusively by local people and which therefore had a negligible impact on mining knowledge in general.

[18] Wong Lin Ken (1965), p. 235. [19] United Nations (1972), p. 69. [20] Mumford (1934), p. 67.

The extreme unpredictability of deposits placed a high premium on intuition-based judgement, honed by long years of experience. In Europe, even as late as the 19th century, the search for coal was often in the hands of practical colliers who had only their experience and their intuition to guide them. The result was that they were very often in error. Nevertheless, with no alternative available, they continued to be listened to and their advice followed.[21] The same situation prevailed throughout Chinese mining well into this century.[22] Intuition and judgement were of course also essential in other areas of mining such as timbering and measures against flooding.

The *ad hoc* character of mining revealed itself not only in the knowledge of deposits but also in the actual techniques employed. Timbering offers a good example. The basics are quite simple, and can easily be learned by doing. The ability to apply that basic knowledge, however, cannot be taught very well at all by means of words; it is learned through practical experience, until much of it becomes an intuition that can deal with any particular case. This was widely true of most other mining techniques as well.[23]

(iii) *The physical and social costs of mining*

With only occasional or partial exceptions such as native metals in placers, the earth does not give up its treasures easily. Few occupations can match mining's reliance on constant application of hard physical labour. Breaking or hauling rock, for a long time the prison activity *par excellence* in certain countries, is no one's idea of an easy job.

Additionally, there is the underground mining environment. Though some might profess to find poetry there,[24] to most people it is singularly unattractive, as well as unhealthy; in Lewis Mumford's vivid characterization, it is 'the first completely inorganic environment to be created and lived in [*sic*] by man . . . Here is the environment of work: dogged, unremitting, concentrated work. It is a dark, a colourless, a tasteless, a perfumeless, as well as a shapeless world: the leaden landscape of a perpetual winter.'[25] Had he been thinking of Chinese mining, Mumford

[21] Porter (1973), p. 332.

[22] The interplay of ignorance, intuition, luck, and practical experience became so thoroughly a part of mining that, until quite recent times, there were many who argued that that was the only way mining could ever be, that 'scientific mining' was a mirage; Porter (1973), p. 337.

[23] For a very insightful discussion of the related problem of conveying craft knacks or secrets in words, see Harris (1976). This was a problem well understood by at least some Chinese from very early times; see Vol. 2, pp. 121ff.

[24] Thus William Ralston Balch (1882, p. 782): 'Can poetry be associated with the deep pits and long underground galleries in which the never ending rows of timbers look like processions of ghosts and the masses of fungus remind you of strange monsters without form, yet of most fantastic shape, as seen in the dim light of the lamps which gleam like stars in the heads of the miners? The answer is yes.' Cited in Francaviglia (1991), p. 18.

[25] Mumford (1934), pp. 69–70. For the most part, the only sense in which miners in China 'lived' in mines was in the long shifts of up to 24 hours or more that they sometimes worked; Wright (1984), pp. 69–70. A major exception, however, was those Shansi coal mines in this century where, because of the bottleneck created by the inadequate winding installations used not only for raising coal and water but also for raising and lowering miners, 'shifts' might last up to 55 days; Wright (1984), p. 170.

might also have commented on the cramped workings that often required miners to enter and work on their knees, or even on their stomachs, where the air could be so foul and lacking in oxygen that lamps refused to stay lit.[26]

Mining that has proceeded any distance underground must often cope with formidable and dangerous natural forces: the weight and pressure of surrounding rock that could cause collapse of the workings; the inflow of water that, at a minimum, added to the unpleasantness of mining but also frequently arrived in quantities that forced the abandonment of mining operations. Particularly in the case of underground coal mining, there was always the possibility of noxious or explosive gases that could appear silently and kill without warning.[27] Even those miners who escaped sudden injury were subject to the diseases such as silicosis and black lung that plague underground miners. What all of this meant in the traditional context was that mining developments that from many perspectives would be regarded as 'progress' (e.g., larger, better organised operations deeper underground) actually amounted to regression when viewed from the perspective of the miners' working conditions. One is reminded of the deplorable conditions of workers in the early factories of the industrial revolution.

Given the inevitable hardships of mining, it is no wonder that most Chinese, when they could, would choose farming or other surface work over mining, though a little shallow mining might be attractive to a farmer as an off-season supplement to his meagre income. Agriculture of course also imposed its demands for hard labour, but the expenditure of sheer brute strength, day-in and day-out, was much smaller than in mining. Most agricultural work consisted of subtle and careful (if repetitive) actions that engaged the farmer in a cooperative effort with his environment. By contrast, the miner often found himself in a battle where he pitted his strength and endurance against the recalcitrant rock. Perversely, it was often the hardest rock that contained the richest ore.[28] What the miner typically needed most was not the cooperation of nature but rather access to more power for subduing his environment. But that was something that the existing technology could rarely provide, and he was left to rely solely on his own muscle power.

Added to the difficulties of the work itself were the social costs demanded by the life of a full-time miner. It was often a life in which violence and fear figured prominently. Ricardo Godoy vividly contrasts the life of Indian peasants and peasant-miners in Bolivia (Map 1):[29]

[26] Only occasionally do we hear of an exception to the dreadful conditions in which most of China's underground miners worked; such was the turn-of-the-century coal mine outside Chungking with its excellent ventilation, its bamboo trolleys riding on wooden rails, and its 'cheery, well-built' miners who could take advantage of hot baths provided free by the enlightened mine-owners; Reid (1901–1902), pp. 31–3.

[27] Even today, about 10,000 Chinese miners die yearly in coal mine explosions; *The Economist*, Nov. 15, 1994, p. 32.

[28] Yen Chung-phing (*1957*), p. 52.

[29] Godoy (1990), p. 52. The parallel with China is of course inexact. We are too aware of the darker side of peasant life in China to idealise its 'calm'. For recent discussions of the rôle of violence in China, urban and rural, cf. Lewis (1990) and Lipman & Harrell (1990).

Even in the style of human interaction, the worlds of agriculture and mining contrast with each other. Life in the village, fields, and pasture is calm (except during festivities), but intercourse in the mine is intense: coarse, manly joking among crew members, bravado in the face of danger, anxiety about finding lodes, depression in failures, worry about accidents, feelings of fear, awesome expectancy, and obsequious humility toward subterranean demons, whose power and capricious will are at once envied and dreaded. Such is the paradoxical world of Andean peasant mining – revered but despised, luring but frightening.

There was also the frequently mobile and rootless condition of miners that flouted the values of family solidarity and native place ties that were so important to the vast majority of Chinese. To be sure, G. William Skinner has made us aware of the great number of 'sojourners' in late imperial Chinese cities.[30] But *their* lives were highly stable compared to the erratic wanderings that often characterised the life of a professional miner. Urban sojourners were able to fit into pre-existing networks that helped them to maintain ties to their native area and to their families. Mining did not usually provide the conditions for the emergence of such networks on a stable basis.

Certainly there were among Chinese miners some who turned to mining to escape the rigours and routine of agriculture or the strictures of agricultural society.[31] Their choice of mining may have been made somewhat easier by a taste for adventure and the rough life together with the hope of striking it rich that throughout history has motivated prospectors and miners the world over. But given the very harsh conditions that prevailed in most of Chinese mining together with the social stigma and common government suspicion of, if not disdain for, miners, we can probably assume that such miners-by-choice made up a distinct minority among the total mining force.[32]

One might even go a step further and suggest that, of all the factors encouraging mining in traditional China, none was of greater importance than the dire poverty that left so many people with no choice but to attempt to eke out a living as a miner. Writing in 1872, the well-travelled Baron Ferdinand von Richthofen commented in regard to the mining and washing of gold (perhaps the most ubiquitous mining activity in China) that only in Yunnan and the surrounding metalliferous area could the gold miner hope to earn as much as could be earned from other kinds of non-agricultural work.[33] Probably in no other country has so much mining been carried on for such minimal returns. Extensive mining operations, as often as not, were a good indicator of poverty rather than prosperity.[34]

[30] Skinner (1976).

[31] For a good expression of this attitude by a man who chose the wandering life of a peddler to farming, see Gates (1987), pp. 133–4.

[32] Among those to whom this probably applies with particular force were the large numbers of young boys sold by their impoverished parents into periods of indentured servitude as miners; see (*k*)(2) below.

[33] von Richthofen (1872b), p. 76; Collins (1922), p. 31. See also Torgasheff (1930), p. 126. We shall return to this point in Section (*k*) below.

[34] Just as a large number of mines might indicate a poor deposit that required a great deal of searching to find winnable ore. Cf. *Han Pin Chi*, ch. 8, pp. 7b–8a; Hartwell (1966), p. 43. Of course, there were many part-time peasant miners who did not find themselves in quite so dire circumstances and had the luxury, like the Indian peasant miners of Bolivia, of working their mines at a pace just sufficient to meet short-term needs or perhaps allow them to buy a few simple extras. But the limited possibilities open to them (meagre deposits, lack of capital to invest in developing mines, etc.) probably kept even these peasants from ever associating their mining activities with a possible improvement of their overall economic conditions. See Godoy (1990), p. 58.

The combination of dire poverty and the precariousness of the living to be made from mining may well have been the greatest obstacle to the use of improved technology in most areas of Chinese mining. As we shall discuss below (Section (*k*)), capital expenses *had* to be kept to a bare minimum, often by accepting miserable working conditions that could otherwise easily have been improved with existing knowledge and techniques.[35]

(iv) *The gap between the best and the poorest techniques*

In some ways, mining can be the most conservative of technologies. Visible evidence of this conservatism is provided by the miner's tools. In all mining traditions, tools changed very slowly when they changed at all.[36] In China, the ubiquitous use of the mattock from early times right down to the Chhing appears to be an example (Fig. 49 and Fig. 60). The simplicity of the tools needed, which inescapably reduced the tool choices available, seems to have been a decisive factor behind this conservatism. Once a basic repertoire of iron tools had come into use, there was little to be gained from minor improvements in the tools; notable improvements had to await the application of inanimate power to machines and tools in modern times.

Conservatism does not characterise the whole story of mining, however. The extreme variety of mining environments and ore deposits, which continually posed new challenges, also encouraged innovation. Innovation also came about through the mobility of the miners, a mobility that promoted exchange of information on better practices (and which at least partly counteracted the miners' propensity for secretiveness) as well as by the lack of a significant miners' literature that might have encouraged overstandardisation of mining techniques.

Thus, while nothing could be done in traditional times to introduce mechanisation at the rock face, opportunities existed and were sometimes seized upon to introduce mechanisation into other mining operations such as drainage, ventilation, and the hauling, crushing and washing of ores.[37] Moreover, while prospectors and miners could not benefit from the insights of modern geology and chemistry, they developed over time a considerable practical experience that provided them with, among other things, a large repertoire of tests for identifying minerals (Section (*f*)(5)).

Another area that would seem to have offered many possibilities for the gradual improvement of techniques was timbering, the methods used to support the roofs and walls of shafts and galleries. Timbering, however, illustrates particularly well the problems of assessing the general level of the technology in use at any given time. We know from a series of important recent archaeological excavations that Chinese miners at least by Warring States times (second half of −1st millennium)

[35] For example, in drainage and ventilation.

[36] For Europe to the 16th century, cf. Smith (1967), p. 143. For China, cf. (*h*)(2)(i) below.

[37] There were in the processes for concentrating ores almost endless possibilites for inventiveness, as appears very clearly in Agricola's *De Re Metallica* (Hoover & Hoover (1912), book VIII). Moreover, none of the great variety of implements illustrated there required 'modern inputs' and all depended on a prolific use of labour. At least in the light of what we know to date, it appears that this was an area where Chinese inventiveness was much more limited than what we see in +16th century central European mining. For further discussion, see (*i*) below.

were using quite sophisticated timbering techniques (Section (*h*)(4)). What we do not know is how often timbering in later periods rose even to the level of these techniques. There was certainly little or no timbering in those thousands of 'rabbit warren' tunnels that never ceased to appall Western observers (though Japanese observers were perhaps more on target in admiring the ability of the Chinese miners to work in cramped spaces and thereby minimise the amount of non-paying waste material that they had to remove from their mines).[38] Is it possible that those advanced Warring States techniques actually represented a peak in timbering practices that failed to be surpassed in traditional times?[39] Indeed, Chinese scholars have suggested that the copper mining technology of Yunnan in the Chhing – the major copper mining region of the late imperial period – displayed *no significant technological advance at all* over what was done in Warring States mines two millennia earlier.[40] Insofar as that is true (and it probably includes an element of exaggeration), it suggests that mining may represent a technology where it is especially dangerous to assume that techniques will improve in a consistent fashion. It was not at all uncommon in traditional China for technological (and scientific) discoveries to be later forgotten. The very same factors that gave rise to the great variety of mining practices in China (size of the country, variations in ore deposits, isolation of the mines, lack of a body of mining literature, limited mobility of those who might have personally transmitted mining expertise) probably also opened the way to retreats as well as advances in mining technology. In any case, over the last three millennia, one could have found at any given moment an extreme variety in the levels of mining technique used in different kinds of mining and in different parts of the country.[41] Unfortunately, the history of traditional mining in China is still far too underdeveloped to permit in this study anything more than occasional and very rough comparisons of mining practices in different parts of China in any given period.

[38] There was also in Europe and England, during the Renaissance and afterwards, a striking gap between the best and worst mining techniques; Mokyr (1990), p. 66. Eventually, mining schools in Europe would contribute greatly to raising the general level of mining practice and hence narrow this gap. It is not at all surprising that, despite the shaky claim by Hu Chhun-thao (*1990*, p. 33) that a *shu-yuan* 書院 or 'academy' established by the Yuan government at the Meng-shan 蒙山 silver mining centre in Kiangsi can be seen as a predecessor of Chinese mining schools, no mining schools were ever established in traditional China, not to speak of a rational science of mining (*Bergbauwissenschaft*) with university chairs of mining! Even in Europe, these developments had to await the +18th century (Vogel & Theisen-Vogel (1991), p. 51; Vogel (1991c), p. 81) when mining knowledge, combining theory and practice, had reached a sophistication (thanks to continuing advances over the previous two and a half centuries) that was well beyond even the imagination of anyone in China before the entry of Westerners on the mining scene in the second half of the 19th century.

[39] Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 95. It is very interesting to note that such a peak *was* arrived at in the Athenian silver/lead mines at Laurium in the −5th and −4th centuries where techniques were used that would not be surpassed in Europe for the next thousand years; Finley (1965), p. 30. Shepherd (1980, p. 177) would even go so far as suggest that Neolithic copper mining in Austria used 'systematic methods of extraction, drivage, drainage, ventilation and preparation of the product [that] would not be out of place in the 19th century, except for developments in illumination and explosives'.

[40] Wu & Hsu (*1987*), Vol. 2, pp. 629–30. One is reminded of the long decline in European mining from the fall of the Roman empire to the +13th century; Nef (1952), pp. 458–9, 468.

[41] A particularly striking example of this phenomenon is provided by early mining in Europe, where underground mining for *copper* may have begun in Rudna Glava and Aibunar in the Balkans even before the inhabitants of Britain had begun digging underground for flint (Map 10). Shepherd (1980), pp. 153–4; Jovanovic (1976). But compare fn. 61 in Section (*e*).

(*b*) OVERVIEW OF MINING IN TRADITIONAL CHINA

(1) THE IMPORTANCE OF MINING IN CHINA

D. S. L. Cardwell once lamented the generally inadequate recognition mining had received for its contributions to European civilisation.[1] The situation is much improved today, due in no small part to something of a 'boom' in Germany during the last quarter of a century in serious academic work on mining history together with increased levels of activity in most other European countries.[2] In other parts of the world, too, mining is increasingly receiving more of the attention its importance deserves. That is now true even for China where such recognition has long been hindered by strong cultural prejudices that encouraged a slighting of the rôle of mining in Chinese history.

The overwhelming importance of agriculture in China led to a strong physiocratic bias among centuries of Chinese officials and writers on economic topics. Agriculture was so unchallenged as the basis of the Chinese economy that other economic activities were often first assessed for their possible baneful effects on agricultural production. Hence the remarkable downplaying of the importance of mining by many who, had they only opened their eyes and minds, would immediately have known better. Not a few Western scholars have picked up the bias of their Chinese sources, explicitly minimising the importance of mining and its production[3] or simply passing over it in silence.

On the other hand, any objective comparison of mining in Europe and in China reveals very quickly that mining in China, for all its importance, did not play as dramatic a rôle there as in Europe, especially in recent centuries.[4] In general, it was not the case that mining areas in China were 'centres of technology and science as well as of financial organisation and business enterprise'.[5] One does not see Chinese mining stimulating major technological and even scientific advance, as it so clearly did in late medieval and early modern Europe.[6] Why Chinese mining did

[1] Cardwell (1972), p. 73.

[2] Two outstanding recent works stressing the contributions of mining especially to European art and culture are Wilsdorf (1987) and Slotta & Bartels (1990); see also the earlier Winklemann (1958).

[3] Cressey (1955), p. 130.

[4] John Nef was correct in emphasising this, though he exaggerated in saying that the Chinese 'showed little disposition to ransack the subsoil for [mineral] riches.' Nef (1952), p. 430. Wilsdorf (1987), despite a sub-title proclaiming it 'Ein illustrierter Streifzug durch Zeiten und Kontinente', actually focuses overwhelmingly on mining in Europe. Undoubtedly, this is not only because European mining has been so much more thoroughly studied than the mining of other parts of the world but also because, objectively, the influence of mining on all aspects of life there since the late Middle Ages was so much greater than anywhere else.

[5] Cardwell (1972), p. 73.

[6] Nef (1952), pp. 429–30 and 462; Cardwell (1972), pp. 73–4; Pacey (1991), p. 69; Pacey (1992), chap. 5; Taylor (1957), p. 27. Thomas T. Read (1933, pp. 252–3) makes the very interesting suggestion that there was here 'an unfavorable contrast between mining where equipment already developed for other uses was usually only slowly introduced underground, and metallurgy, which developed its own equipment and methods that later proved useful in other industries.'

not perform this function is a major question to which we shall return often in the course of this study.

(2) Total Mining Production and its Labour Force

Little reliable evidence exists on which to base estimates of total mining production in China for any period before this century. This is especially true for the centuries before the Sung, for which we have virtually no figures that even purport to reflect total production.[7] We can be fairly confident that such figures have not survived because they were never compiled in the first place, a task that would have been beyond the government's capabilities at that time. From the +11th century (Northern Sung) on, such global totals do begin to show up in the sources, but they are so questionable on so many counts that any efforts to calculate total production must usually remain more or less 'guesstimates'. In our discussion of the various minerals and materials mined in traditional China (see Section (*e*) below), we shall present some of these estimates. For the moment, however, we can use as something of a benchmark the estimates by Boris Torgasheff of total mining production in China around 1925 (Table 2). The figures are probably the best that could have been assembled given the information available in the mid-1920s and, thanks to the efforts of the newly established Geological Survey of China, were probably far better than anything that could have been attempted as little as a decade earlier. One would of course not want, without contemporary corroboration, to rely on these production figures as a reflection of the magnitudes of production in the +18th or 19th centuries, much less in earlier periods. But they probably do, with obvious exceptions such as the flourishing copper industry in the high Chhing (see Section (*e*)(1)(i)(ε)) and the non-existent tungsten mining, reflect fairly well the relative size of different sectors of the mining industry in the Chhing period and perhaps to some extent earlier periods too. It should be remembered that, even in the 1920s, most of Chinese mining (except for coal mining) still relied on native methods.

With these production estimates, Torgasheff then went on to use what he called the 'proportion of output to labour method' to try to estimate what percentage of the total Chinese population was engaged in mining. That is, he compared the efficiency of Chinese and American mining labour and came to the conclusion that 'in Chinese mines, taken as a whole, the average efficiency of labour constitutes not more than *five per cent* of that of American labour; a *little more than ten per cent* is the efficiency of labour in quarries.'[8] Using the estimated production totals and per capita efficiency figures (i.e., output per miner), Torgasheff came to the conclusion that approximately one-half of one per cent of the total Chinese population (2,100,000 people) was involved in mining (Table 3). Actually, the number and

[7] This holds true even for total production of individual mines. The government was far more interested in what revenues it could extract from a mine on a regular basis than in production figures, which had an inconvenient tendency to vary considerably from year to year.

[8] Torgasheff (1930a), p. 415. Italics in original.

Table 2. *China's estimated mineral production, 1925 (metric tonnes)*

Precious metals		*Miscellaneous non-metallic minerals*	
Gold	11	Alunite	11,022
Silver	1	Asbestos	423
Non-ferrous metals		Rock crystal	7
Copper	2,345	Fluorspar	4,498
Tin	9,200	Gypsum	67,000
Lead	3,503	Mica	200
Mercury	470	Nitrate of potash	15,000
Arsenic	1,547	Phosphate	13,719
Zinc	18,542	Pigments	?
Magnesium	53,773	Pyrite	3,066
Antimony	21,423	Soda	91,500
Bismuth	60	Sulphur	2,348
Ferrous metals		*Rocks, clays, etc.*	
Iron	c. 1.5–2,000,000	Raw clay	15,000,000
Manganese ore	75,000	Limestone	15,000,000
Tungsten ore	7,044	Stone, gravel, etc.	54,000,000
		Kaolin	423,115
Precious and semi-precious stones	?	Pottery clay	585,000
		Talc	51,516
Abrasives	2,583	Soapstone	3,000
		Felspar	30
Quartz (for glass)	4,694	Calcite	93
		Fuels	
		Coal	35,000,000
		Petroleum (barrels)	100,000
		Natural gas	?

Based on figures given in Torgasheff (1930), pp. 41–4. Estimates include Manchuria. Figures believed by Torgasheff to be, if anything, conservative. On the other hand, a US Bureau of Mines survey for 1934 gives uniformly lower estimates; Cressy (1955), p. 132. Note, however, that this latter survey gives a higher estimated production of silver than of gold (for all China excluding Manchuria and Taiwan). This is almost certainly a major error, and raises doubts about the other estimates.

Table 3. *Estimated amount of mining labour in China, early 20th century*

Categories	Total number of miners	Percentage of population[a]
Non-metal and metal mines	1,200,000	0.26
Quarries	250,000	0.05
Salt, pottery & porcelain clay mines, etc.	650,000	0.13
TOTAL	2,100,000	0.44

[a] Based on a total estimated population of 450,000,000. (The figures for the percentage of population working in 'Salt, pottery & porcelain clay mines, etc.' were accidentally reversed in the original table, i.e. 0.31 instead of 0.13.) Torgasheff (1930a), p. 416. For qualification of these figures, see text.

proportion of Chinese in mining at that time were probably significantly higher since Torgasheff's figures excluded most of the Chinese engaged in mining on a less than full-time basis.[9] One can only guess how much Torgasheff's figures need to be modified but we would probably not be very far off in suggesting that approximately one per cent or slightly more of China's population was active in mining early in this century.

(3) The Predominance of Small-scale and Seasonal Mining

Chinese mining in traditional times was overwhelmingly characterised by small-scale operations. Torgasheff's description of the situation in the 1930s was, if anything, even more true for earlier periods: 'Great as the total number of Chinese mines is, the majority of them are nothing but small native enterprises employing a very limited number of men. The mines are scattered throughout the country, and the centres of a large accumulation of miners are rare.'[10] Individual mines typically had no more than ten people (perhaps all family members) working them; often enough it would be as few as two or three (Fig. 1).[11] Even operations that were quite large in terms of total production were usually organised into many smaller works.[12] Of course there were exceptions (Fig. 2). For example, at the Fang-shan 房山 coal mines just south west of the city of Peking in the Chhing, coal mines with only 80 or 90 workers were considered small.[13] But the norm for most kinds of mining in most areas was very small mines. This was due mainly to the small and irregular character of most ore deposits in China[14] but was undoubtedly further encouraged in many cases by erratic markets with considerable fluctuations in demand, a situation that made the higher overhead costs of large mines unsupportable.[15]

[9] Torgasheff himself recognised this problem (1930a, p. 782, footnote).

[10] Torgasheff (1930a), p. 923. H. F. Dawes (1891, p. 335) notes that one reason for small mines was that many – he would say 'most' but may be referring only to silver mines in Mongolia, the subject of his report – of the mines were illicit. This was probably true throughout most of the imperial period, with large numbers of miners either violating government prohibitions on mining or not paying taxes on their production (cf. below, (*l*)).

[11] Junghann (1911), pp. 11–12. Arthur Moore-Bennet (1915, p. 217) presents a somewhat idealised account of the breakdown of tasks among family members in south China family mines early in the 20th century: 'These mines are usually worked by a family, the father and elder male children being employed in winning the ore, the smaller children in labouriously carrying the spoil up the burrow, in small cloth baskets, the mother and elder female children in timbering the mine [!], and converting wood into charcoal [for roasting and smelting] . . . and the old folks in crushing the ores and in smelting.'

[12] Cf. especially Section (*e*)(2)(ii)(δ) on the Ko-chiu tin mines. Here we might mention the case of copper mining at Thang-tan 湯丹 (Tung-chhuan 東川): with a maximum of slightly over 30,000 workers, it was the largest 'mine' in Yunnan during the Chhing. Yet this 'mine' actually consisted of a collection of mining shafts, many several days journey one from the other. Most of the individual shafts were worked by only five to ten men. Essentially then, the Thang-tan mine was no interconnected commercial enterprise but more like an administrative fiction, consisting of all the mining operations for which a single government official from the Copper Office was responsible. Lee (1987), pp. 236, 243. A rather different example, with much more intensive mining but still in organisational terms a highly decentralised production, is described by Tegengren (1924, p. 165): at the coal mines of Chin-chheng 晉城 in southern Shensi, one pit every 1,000 to 2,000 sq. m was not uncommon and, in one area, pits were dug on an average of one every 28 sq. m. One mountain in Honan, because of its many shafts side-by-side, had acquired by the 19th century the name Sieve Flower Mountain (*Shai-tsu To shan* 篩子朵山); Wen Kuang (*1980*), p. 427. See also Brown (1923), p. 106.

[13] Lü Tai-ming (*1986*), p. 171. [14] Cf. (*d*)(4)(i) below. [15] Neilson (1982), p. 5.

Fig. 1. A small coal field in Kiangsi in the 1920s. The coal seams are 30–50 metres below the surface and must be mined by means of shafts and drifts. Over each shaft, a structure is built to protect the shaft and its windlass and to provide living quarters for the miners. (For a view inside one of these structures, see Fig. 87.) In this case, seemingly rather exceptional in Chinese mining, fences mark off separate claims leased out by the owner of the land in exchange for a share of the product. This installation is an example of the modest scale typical of most mining in traditional China. Hommel (1937), p. 2, fig. 1.

Besides its small scale, much of Chinese mining also had a clear seasonal character that derived both from climatic conditions and from the structure of the Chinese economy. In many places, it was simply impossible to mine year-round. Water was the most common problem. Few areas in which placer mining was carried on had water available in all seasons. Even underground operations often depended on an availability of water for concentrating the ore prior to its delivery to the smelter. Thus, at the Ko-chiu 箇舊 tin mines, there was a clear seasonal sequence in which mining, ore concentration and smelting each were carried on in certain months but not over the rest of the year.[16] The same phenomenon was to be seen at Tsun-hua 遵化, the major iron production centre of the Ming.[17]

The other reason for the marked seasonality of so much of Chinese mining was the overwhelmingly agricultural character of the Chinese economy. Probably more than in any other country, mining in China was carried on as a side occupation by people whose main source of livelihood was agriculture. Many therefore took up mining after the harvest was in but returned to their fields for the spring planting.[18]

[16] Cf. Section (*e*)(2)(ii) below. During the winter, most of the mines and smelters were completely shut down and many of the workers returned to their homes in other places.

[17] Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 1, pp. 189–90.

[18] South China, of course, offered more opportunity for agriculture in the winter. This may have meant that the numbers of peasants engaged in mining as a supplementary occupation was proportionally smaller than in the north. Along with the richer mineral deposits of south China, this may also help explain the impression that the greater proportion of China's full-time, more highly skilled miners came from the south. Nevertheless, there is sufficient evidence to show that seasonal mining by peasants was also important in the south. Cf. Section (*k*)(1) below and Eberstein (1974), pp. 144; 146–7.

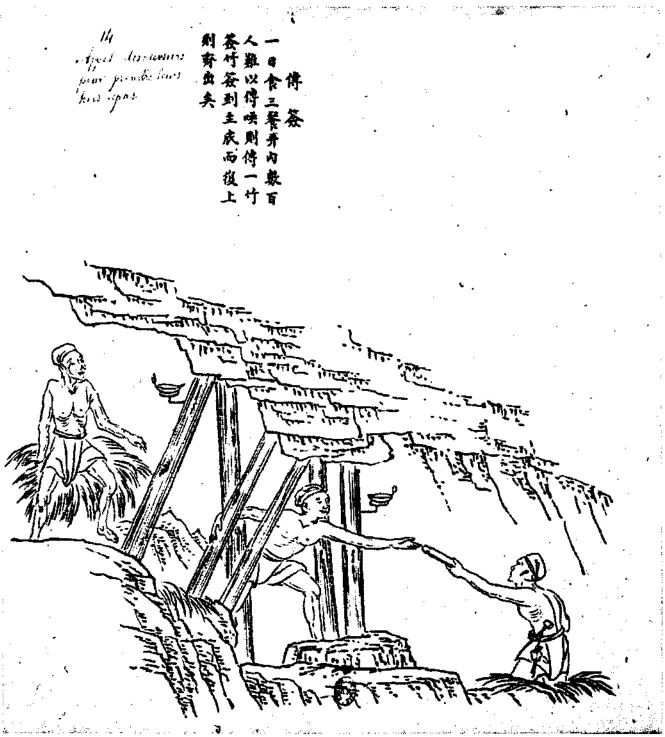


Fig. 2. Getting the word that it was mealtime to workers in a coal mine of some size (with several hundred men working underground [*ching nei shu pai jen* 井內數百人]). A bamboo slip is here passed from the miners closest to the surface to those farther underground. When it reaches the deepest recesses of the mine, those miners begin walking out for their meal, collecting the other miners as they go. The implication is that all the workers left the mine for a meal at mid-day, though one wonders how often this was actually the case. Nevertheless, Slessor (1927, p. 58), in discussing non-ferrous metal mines in south China, explicitly notes that 'the miners never eat below ground'. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 117, pl. 1.

Others even engaged in mining during slow periods between planting and harvest.[19] The widespread participation of peasants in mining had many important implications for how mining developed in China, the most important of which may have been the persistence of peasant ways of thinking among the miners.[20]

[19] As one proverbial saying had it: '*Nung hsi wei chih; mang tse chih*' '農隙為之；忙則止' ('In farming's slack time carry on [mining]; when it gets busy then stop.'); Lü Tai-ming (*1986*), p. 164.

[20] Cf. especially Section (*k*)(4) below.

(c) SOURCES

[H]istory is a bag of tricks which the dead have played upon historians. The most remarkable of these illusions is the belief that the surviving written records provide us with a reasonably accurate facsimile of past human activity. *Lynn White*[1]

(1) The Contribution of Archaeology

When work on this study began at the end of the 1970s, there seemed little chance that I would be able to say much about the early phases of mining technology in China. I was aware that there was pitifully little on mining in the written works that survive from before the Han, that is, before the −2nd century.[2] Even much later writings were disappointingly lacking in details on actual mining practice. And for the entire period before this century, only two surviving Chinese works, both relatively late, include illustrations of mining.[3]

However, although unknown to me at that time, the first published reports on the excavations of Chou (and perhaps even Shang) copper mines at Thung-lü shan 銅綠山, just south of the Yangtze River in Hupeh, had already begun appearing in 1975. That first great discovery was soon followed by many others, leading to a flood of excavation reports and studies of early mining in China. Because the traces of ancient mining efforts are often very durable, even written in the stone itself, mining archaeology can be an indispensable, and even the sole source of knowledge about the past of mining. What we now know about even the details of early mining in China rivals or surpasses our knowledge of other early mining traditions. Indeed, the combination of scarce information in the written record together with the tendency of Chinese archaeologists to focus mainly on very early mines means that we sometimes know more about specific mining techniques (e.g., timbering) in earliest times than about what followed in later centuries.

Fortunately, no period in Chinese history witnessed more dramatic developments in mining technology than the −1st millennium, precisely the focus of most of these mining excavations. It is fortunate, too, that the small-scale nature of much of Chinese mining even today, relying often almost exclusively on human labour rather than on machines, has meant that archaeological remains that might easily

[1] Lynn White (1962), p. v.

[2] J. R. Forbes, the renowned expert on ancient technology, bemoans a similar paucity of information on mining in Greek and Latin works; Forbes (1963), p. 104. In fact, compared with early Chinese writings, the Western sources are quite informative.

[3] Vogel (1991), p. 163. The two works are the +17th century *Thien Kung Khai Wu* (*TKKW*) and the mid-19th century *Tien-nan Khuang-Chhang Thu Lueh*, for both of which see below.

have been obliterated in larger mining operations have often been recognised and made available for study before being seriously damaged.[4]

With the considerable contributions of recent archaeology to our understanding of traditional Chinese mining, it might appear ungrateful to point out some of its limitations. Nevertheless, because they have influenced the kind of story we could tell below, they must at least be mentioned.[5]

At the outset, we should recall that mining archaeology is still at a very early stage in China.[6] There have not been any organised archaeological expeditions to search for mining remains. What has been found has been found mainly by chance. One result is that the excavated early mines in China date almost exclusively from a period when metalworking was already well-developed.[7] In contrast with the early history of mining in Europe for example, where we have learned so much from the excavation of flint mines,[8] we still know almost nothing about Neolithic mining in China.[9]

One must also admit that the quality of the excavation work and/or the published reports sometimes fail to measure up to international standards, for a number of reasons. The newness of the field of mining archaeology means that many of its practitioners suffer from a lack of specialised training as well as being relatively inexperienced. This can sometimes lead to an excessive concern with details while the broader significance of the data is neglected.[10] Moreover, without an overall framework of understanding, even very important details sometimes go unnoticed or unreported.[11] An excessively narrow approach is also fostered by the general absence of inter-disciplinary approaches in Chinese archaeology. For example, mining engineers are seldom present at excavations of mines.[12] Intermittent consultation with experts is not always a satisfactory substitute.[13]

Funding practices, often influenced by nationalistic motives and even questions of local pride, can also skew archaeological efforts. Funds from the central government, sometimes in the form of bonuses, tend to flow to those people who come up with 'major finds', sites that produce spectacular artefacts or art works: bronzes, jades, scuptures,wall-paintings and the like. By contrast, excavations of what might by scholarly standards be a very important site, say the remains of an early bronze

[4] On the other hand, we have examples like the important Kang-hsia 港下 mine in Hupeh, dating from perhaps as early as the −9th or −8th centuries, where only the remains of the lower levels of the ancient workings survive, the upper levels having been removed before preservation activities began; Vogel (1991), p. 155. Moreover, there have been, not surprisingly, many cases where workers have failed to recognise important remains; see Wagner (1993), pp. 83, 146.

[5] For comments along the same lines by two outstanding Chinese scholars, see the remarks of Huang Chan-yueh, translated in Wagner (1993), p. 150, and An Chih-min (*1993*), p. 1110 and *passim*.

[6] Development may be painfully slow, but we may hope it will not be as slow as has been the case in the West; Weisgerber (1989), p. 79.

[7] Another result is that *all* of the major excavated early mines are copper mines.

[8] See, e.g., Bosch (1979) and Shepherd (1980), chaps. 2 and 3. [9] Vogel (1991), pp. 163–4.

[10] Even the handling of details often lacks consistency, as reflected in the sometimes wildly inconsistent terminology applied to early artefacts; Wagner (1993), p. 150.

[11] For very useful recent Western attempts to provide explicitly such frameworks, see Cranstone (1994) for surface mining and Weisgerber (1989) for early mining in general.

[12] Or metallurgical specialists; Anon. (1994), p. 86.

[13] Mining expertise is especially necessary because, as Robert Shepherd points out, mining sites typically provide a paucity of artefacts, making necessary a great reliance mainly on the 'geometry of the excavation'; Shepherd (1980), p. 249.

foundry, may have great difficulty getting funded because what survives are only what appear to non-specialists to be rather unremarkable remains of furnace walls or slag deposits.

The allocation of scarce funds also influences what gets published. There are cases where important information from sites excavated decades or even a half-century ago has yet to be published.[14] And it is not only the intrinsic importance of the sites as seen by bureaucrats in charge of funding that counts. Any excavation that gains the attention of archaeologists or art historians outside of China stands a much better chance of gaining support. On the domestic side, considerations of local pride and inter-provincial rivalry also affect both funding and the interpretation of results. There has been a real competition among provinces for the prize of having the earliest evidence of metallurgy in China, and this has clearly coloured what data has been presented in reports, how it has been presented, and how it has been interpreted.[15] The same is true for other technological developments: Chinese archaeologists sometimes seem, at least from the information in their reports, to be rather quick to postulate the use of firesetting on the basis of ambiguous remains of charcoal that could just as well have originally been torches for lighting or the fuel for fires to induce better ventilation. Those of us who rely on these reports must, in the words of Donald Wagner, '[be] careful to maintain a critical attitude, constantly bearing in mind what sort of data might be missing from the published record and what other interpretations may be possible.'[16]

Local pride has had one very positive result in that most provinces in China today have their own provincial archaeological journals, and this has opened the way to much more publishing in archaeology. Unfortunately, even within China itself, the circulation of these journals is often very limited. They thus do much less than they might to diminish another aspect of the fragmentation of archaeology: archaeologists in one part of the country are often not very familiar with what is going on with similar excavations in other parts of the country.

(2) Theoretical Writings, Especially by Alchemists and Pharmacologists

> the really great efforts of ancient science were not in theorising about nature and materials but rather in harnessing materials technologically to man's use.
>
> *Arthur Steinberg*[17]

When discussing in the introduction the uniquely *ad hoc* character of mining, we noted that it is not rare for any given mine to differ strikingly even from nearby

[14] Wagner (1993), p. 14.

[15] Barnard (1991), p. 8, fn. 11. There is also the further problem, hardly unique to China but perhaps somewhat more prevalent there, that the very excitement and enthusiasm that accompany an important find can influence the presentation of results; Barnard (1993a), p. 48, fn. 2.

[16] Wagner (1993), p. 15. Both Wagner and Barnard set an enviable standard for critical reading of archaeological reports.

[17] Steinberg (1976), p. 536.

mines in generally similar conditions. Despite the extreme variety of the mining environments, however, miners could hardly do without at least some rules of thumb to suggest to them where and how to go about their task. For example, the experienced prospector looking for metal ore deposits wasted little time searching in low country but instead headed into the hills, seeking out perhaps the glossy, acid igneous rocks that were often a good indicator of mineralisation.[18]

Over time, the mining community in any area with an active mining industry – and China from the Neolithic onwards had many such areas – inevitably developed a body of mining lore and accepted practice on which miners drew for guidance. Of course, not being written down, it suffered from the defects that commonly accompany oral transmission. Amorphous and fragmentary, it had as many versions as minds in which it was housed. Inevitably, inaccuracies and inconsistencies abounded. In any case, there were surely here and there especially intelligent and experienced miners who clearly surpassed their fellows both in breadth and in depth of knowledge.[19] The surviving written record in China unfortunately tells us very little about the character of this expertise.[20] In part, this is a reflection of the already remarked general lack of interest in, if not disdain for, mining on the part of educated Chinese before the 19th century.[21] Unlike many members of the educated élite in Renaissance Europe, they never looked on the experiences of miners and smelters as a means of gaining a better understanding of the workings of nature.[22]

Perhaps equally or even more important was the difficulty even in the best of circumstances of explaining craft skills in words, a problem arising from the intuitive character of so much of mining.[23] Only with the introduction of modern Western science and technology starting in the second half of the 19th century, together with the opportunity for at least a small number of Chinese students to study science abroad[24] and the attempts to create a modern republic after the overthrow of the Chhing dynasty in 1911, does mining (along with geology) become an object of study for at least a few educated Chinese. Before then, there simply was no

[18] For this and other examples, cf. (*f*)(3) below.

[19] Philippe Braunstein (1983, p. 577) refers to this as a 'sort of general know-how' that was 'an intermediate culture between science and practice'. This formulation is not without its problems, but the concept of a kind of knowledge that, while surely less than what we would recognise as scientific theory, nevertheless was capable of useful generalisations that went beyond mere empiricism seems to be worth further exploration.

[20] Vogel & Theisen-Vogel (1991), pp. 51–2.

[21] Even where one can detect the emergence of a certain amount of expertise among government officials, as in the administration of the Yunnan copper mines in the Chhing, it was an expertise that was above all 'theoretical and bureaucratic'; Vogel (1987a), I.2.

[22] Vogel (1991c), p. 81.

[23] See above, (*a*)(2)(ii). J. R. Harris has very astutely analysed this problem in the context of skills related to the coal industry during England's early industrial revolution; Harris (1976). Harris emphasises the contrast between England, at the forefront of the industrial revolution but remarkably lacking in technological literature, and France, lagging behind industrially but prolific in technological writings of which the 'Descriptions des Arts et Métiers' and the 'Arts et Métiers' sections of the +18th century *Encyclopédie* are only the most outstanding examples. For our purposes, Harris' article is a salutary warning against the unexamined assumption that, had there been more of a mining literature in China, mining itself would have been more advanced.

[24] Furth (1970), p. 12.

significant body of writings of any kind on mining *per se*, and virtually none in which the writer was motivated by a desire to improve mining practice.[25]

The contrast with the prolific writings on agriculture is striking. Agriculture was universally recognised as the basis of life in China, and it was assumed that a more productive agriculture would inevitably translate into a better life for the people at large.[26] Thus, from the very beginning, Chinese agricultural treatises, like their Roman counterparts, aimed to present and encourage the use of good practices that were broadly, if not universally, applicable.[27] Mining, on the other hand, not only drew much less interest but also, precisely because of its overwhelmingly *ad hoc* character, offered in its early stages little in the way of broadly applicable knowledge and techniques that invited codification in writing.[28] In later periods, when there existed a stock of empirical knowledge that could usefully have been compiled into manuals, there were few changes in the Chinese intellectual climate to motivate writers to take up the topic of mining.[29]

What existed in China before the 19th century by way of generalisations or theories relating in some way to mining has come down to us above all in the writings of alchemists and those of medical men, especially the compilers of pharmaceutical

[25] The one exception that immediately comes to mind is the *Chin Thung Yao Lueh* (Essentials of Steeping Copper), written at the end of the +11th century. It described the process of precipitating copper in mine waters onto iron. (See below, (*j*).) Unfortunately, this work was lost already in the Yuan or shortly thereafter and could therefore play no rôle in encouraging similar works devoted to one or another aspect of mining. There seem to be no works on mining or smelting written between the Yuan and the mid-19th century, when Wu Chhi-chün published his *Tien-nan Khuang-Chhang Thu Lueh* (c. 1845), that contain a serious discussion of the technology; Vogel (1991c), p. 82. This is true of all four works prompted by the flourishing copper mining of Yunnan in the +18th and early 19th centuries (*Yun-nan Thung Chih* 雲南銅志, +1736; *Thung-Cheng Khao* 銅政考, c. 1755; *Yun-nan Thung Cheng Chhüan Shu* 雲南銅政全書, 1787; and *Tung Cheng Pien-Lan* 銅政便覽, 1828) which deal only with fiscal or administrative matters such as quotas, copper purchase, transport regulations and the like.

[26] It also deserves mention that, in striking contrast especially to late medieval and early modern Europe, miners are almost entirely absent from traditional Chinese poetry and fiction. Peasants, of course, are quite well represented.

[27] Vol. 6, pt. 2, p. 89.

[28] Of course, there is also the very important question of who would have had the competence and the motivation to produce such writings, and who would have been their prospective audience. We shall return to these questions below.

[29] Even if there were occasionally members of the literate élite who developed some interest in mining, they were hardly likely to write about it. Most writers in China, as elsewhere, wrote to be read. But the potential readership for a work on mining would, at any time in Chinese history, be tiny and inconsequential, just the sort of thing that Sung Ying-hsing complained of in his Preface to the *TKKW* (Sun & Sun (1966), p. xiv). Francesca Bray has noted that the invention of printing had dramatically different results for agricultural writings in China and in Europe: much greater dissemination of existing works but relatively few new works in China vs. 'a quantum leap in the number of agricultural works produced' in Europe. She places great emphasis on the emergence in Europe of a new audience of 'proto-capitalist' farmers interested in new agricultural works that, unlike the treatises of the great Latin writers so prominent in the middle ages, presented specific information applicable to particular regions of northern Europe. (Vol. 6, pt. 2, pp. 85, 88–9.) Something similar occurred in Europe with the early modern capitalist mining boom that began in the late +15th century and brought forth a new audience for works on mining, one that included wealthy investors who lacked knowledge of mining and metallurgy, rulers with regalian rights who sought to develop mining in their territories, and literate practitioners of mining whose knowledge was key to the profits of their employers, as well as to their own status and income. (See Long (1991), p. 325 and *passim*.) Needless to say, nothing like this kind of new audience for mining works ever appeared in China before the 19th century nor was there any significant government support for writings on mining as was the case in Renaissance Europe where 'active promotion of mining and metallurgy and the encouragement of technical authorship went hand in hand'; Long (1991), p. 330.

knowledge.[30] In their efforts to describe the real or supposed rôle of minerals in achieving alchemical goals or in healing illnesses, these two groups went further than other writers in formulating generalisations about minerals.[31] But even a cursory look at these writings immediately raises doubts about the extent to which their ideas related to the actual practice of mining. To anticipate our conclusion, it will be argued here that little of the theorising by these writers can be taken to reflect the thinking of the miners themselves or to have had any significant influence on their thinking.[32]

In most cases, what miners wanted to know about minerals was something quite different from that which interested alchemists, pharmacologists and healers. If Nathan Sivin is correct, the goals of China's alchemists, 'more spiritual than cognitive or utilitarian', could hardly have had less to do with the goals of miners. Those alchemists who carried out the chemical manipulations of external alchemy (*wai tan* 外丹, in contrast to internal alchemy, *nei tan* 內丹, with its meditative techniques) characteristically focused on 'making chemical models of cosmic process, with the time dimension telescoped so that the great cycles of time could be witnessed [and contemplated] by the adept.' Their goal was essentially spiritual self-cultivation, developing the ability to 'encompass the *Tao* with their minds' and in that way to become one with it.[33] Collecting facts about nature through empirical observation or trying to understand it theoretically seems to have had little importance for them.[34] Most of the knowledge they needed for their manipulations could well have been obtained for the most part rather passively from 'craftsmen' (metallurgists to be sure, but perhaps also miners) and medical men.[35]

In the area of Chinese writings related to medicine, Paul Unschuld distinguishes three types: works that deal with medical theory, those that offer prescriptions, and pharmaceutical writings.[36] The pharmaceutical works, which constitute well under

[30] In a very general way, these two kinds of writings are similar to the first two of Pamela Long's three categories of mining and metallurgical literature in early modern Europe: alchemical writings and 'recipe books', which gave recipes and procedures for assaying and separating metals, for dyeing, for mixing medicinal remedies, etc. Her third category, 'the more formal exoteric treatises and pamphlets' appeared in Europe for the first time in the +16th century but, with the exception of the +17th century *TKKW* and the 19th century *Tien-nan Khuang-Chhang Thu Lueh* (Wu Chhi-chün (*1845*)), were absent from China before the 20th century; Long (1991), pp. 320–2.

[31] We have seen (Vol. 3, p. 643) that mineral remedies appear already in the first of the great pharmaceutical works, the *Shen Nung Pen-tshao Ching* 神農本草經 (Classic of Pharmaceutics of the Heavenly Husbandman) which dates from the Han and describes 46 inorganic substances, ranking them into three groups according to their supposed therapeutic effectiveness. Cf. also Unschuld (1986), p. 21 which gives a total of 42 inorganic substances and notes the likely impossibility of ever arriving at a definitive count.

[32] For a fascinating discussion of how the absence of links between those who wrote and those who worked hindered *both* the growth of geology *and* the rise of scientific mining in the England of the industrial revolution, cf. Porter (1973).

[33] Sivin (1990), p. 13; Sivin (1977a), pp. 111–12.

[34] In this they could not have contrasted more with those many Renaissance philosophers, artists, discoverers and inventors who burned with a desire to understand the actual workings of nature and to formulate explanatory theories that conformed with actual experience. See Suhling (1977), p. 570.

[35] *Ibid.*, p. 14. Unfortunately, we are still almost totally uninformed about just what and how much the alchemists borrowed from craftsmen (and physicians); Sivin (1986), p. 154.

[36] Unschuld insists, rightly I think, that one should avoid the common practice of calling the last group 'pharmacopeias'. Despite occasional government support for their compilation, Chinese governments never attempted to grant these works legal status and to require that pharmacists or medical practitioners adhere to them, as was the case with the first Western pharmacopeia, published in Nuremberg in +1546, and all of its successors; Unschuld (1986), p. 47.

20 per cent of all Chinese medical writings, are nevertheless the most interesting for our purposes.[37] This is the famous *pen-tshao* 本草 literature. Because the Chinese from earliest times made extensive use of mineral drugs in medicine, these works provide a great deal of factual data as well as speculations on at least those minerals that were seen to have a medical use.

Pharmaceutical works over the centuries differed in their format and content as their compilers also differed considerably in the extent to which they relied on earlier literary sources or made an effort to learn directly from people who had hands-on experience with drugs. In general, the pharmacologists were more interested than the alchemists in certain kinds of questions that might also be of interest to miners, such as where one could obtain drugs, including minerals used as drugs, what were the identifying characteristics of different minerals, how one could determine whether they were genuine or whether they had been adulterated. Thus, to give but one example, Thao Hung-ching 陶弘景, whose life spans the last half of the +5th and the first half of the +6th centuries, could already note that potassium nitrate can be distinguished from other salts because of its purple flame.[38]

With that said, however, it must still be recognised that the interests of the pharmacological writers seldom coincided with what miners wanted to know. Though one can find in their writings material having to do with the identification of minerals, or prospecting for them, there is virtually nothing on actual mining practices. The divergence of interests is even more noticeable when the pharmacologists left the realm of observation or description to offer theoretical explanations.

It was not that this theorising was necessarily condemned to lack practical value. In premodern China, theories about the natural world *were* sometimes quite closely linked to practical application. In general, Chinese medicine retained a very practical orientation in which 'theory and therapy were never sundered'.[39] Mathematical astronomy, with its emphasis on making celestial phenomena predictable, necessarily relied on repeated, careful observations.[40] Miners would have been very much attracted to theories that included a strong predictive element, that could above all have served as usable tools to help them find and follow deposits of minerals. Here, even a few very basic geological principles could have been a great help.[41]

One area of geology that has been of great help to modern miners and that would not have been beyond some degree of comprehension by the Chinese even without

[37] Unschuld (1986), p. 2. In Unschuld's scheme, the prescription literature is distinguished from the pharmaceutical writings in that it focuses on the combining of drugs to combat disease while the pharmaceutical literature centres on individual drugs and regularly discusses how and where that drug is obtained and processed to the point where it can be applied for medical purposes. Of course, these two categories can and do overlap.

[38] See below, (*f*)(5)(vii). [39] Sivin (1988), p. 57.

[40] Nakayama & Sivin (1973), p. xxv; Nakayama (1984), pp. 4–5.

[41] It cannot be too strongly stressed that the problem was *not* a lack of acute observation of geological forms. If we are able to identify often quite precisely geological structures rendered by Chinese painters (cf. Vol. 3, pp. 592–8), there is no reason to believe that prospectors and miners, alchemists and pharmacologists, were any less capable of accurate observation. The problem was accounting for those forms, explaining how they came to be, and what connections this might have with mineral deposits. In short, theory with real explanatory power. No Chinese in traditional times took more than a hesitant step or two down this road.

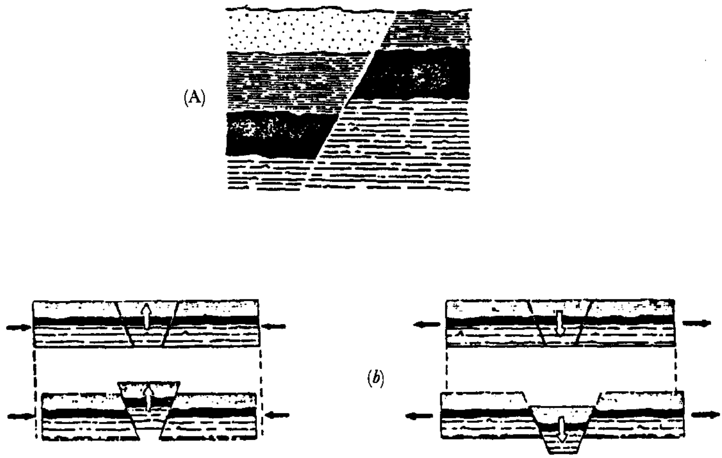


Fig. 3. Faults resulting in a break in a deposit. (A) As a result of a fault or dislocation, the beds, here including a coal seam, are torn and mutually displaced along the plane of dislocation; (B) Formation of a reverse fault by compression (*a*) and a normal fault by tension (*b*). Stočes (1958), Vol. 2, figs. 31–2.

modern scientific understanding is that of earth movements and their resulting faults, together with the fact that deposits are sometimes consistent in their appearance in different beds.[42] We now understand that faults are the result of pressures acting on the earth's crust that cause rock to fracture and the two sides of the fracture to slip past each other (Fig. 3). Even without an understanding of the basic forces involved, the Chinese lived in an area where frequent earthquakes provided them with a superb laboratory for the study of this phenomenon.[43]

Faults are of great importance to the miner or prospector. To begin with, faults can be a good indicator of the presence of minerals. At least some Chinese miners as early as the Warring States period recognised this: at the ancient copper mining complex of Thung-lü shan 銅綠山, the excavations were very skilfully concentrated in a fault zone.[44] Moreover, some understanding of faults, especially their different forms depending on whether they result from compression or tension (Fig. 4), can also be very useful in following up displaced deposits.[45] Without that understanding, Chinese miners were often forced to abandon a deposit when they met with a displacement of ore resulting from a fault.[46]

[42] Of course, without sufficient geological knowledge, miners would sometimes be misled by the lithological similarity of rocks that were in fact quite different; cf. Torrens (1984), p. 90. Here, a little knowledge could be a deceptive if not a dangerous thing.

[43] Living in Persia, a notoriously earthquake-prone area, Avicenna in the +11th century came to ascribe the formation of some elevated terrains to earthquakes which can suddenly raise a part of the land. Cf. Vol. 3, p. 603.

[44] Yang Wen-heng (*1978*), pp. 306–7.

[45] Stočes (1958), Vol. 1, p. 42. Faults can also distort deposits without breaking them; see Fig. 4.

[46] Cole (1916), p. 370; Slessor (1927), pp. 60–1. Across the Eurasian continent, at Laurion in Greece, miners also often made no effort to follow a vein after even a small fault had caused only a slight displacement.

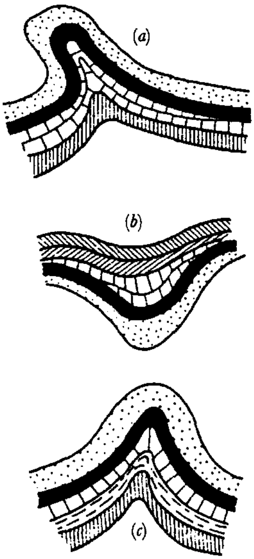


Fig. 4. Folding resulting in the bending but not the breaking of a deposit. (*a*) Overthrust fold; (*b*) Syncline, (*c*) Anticline. Shepherd (1980), p. 10, fig. 4. Both this and the previous illustration apply especially to bedded deposits, though the same forces can of course similarly affect vein deposits.

Chinese miners could also have carried on their mining more effectively if they had had a better understanding of the shapes of deposits.[47] Here too, at least some systematised understanding was possible even without the contributions of modern geology, geophysics and chemistry. Indeed, we know from the *Tien-nan Khuang-Chhang Thu Lueh* that, at least by the mid-19th century, the miners in Yunnan had gone some distance toward not only classifying the shapes of deposits but even using those shapes to judge their likely quality.[48] But such empirical knowledge of faults and ore deposits, which had at least the potential to awaken new ways of thinking about minerals in the earth, never made any impact on Chinese writing about the natural world, for at least two reasons.

The first is that China's proto-earth scientists of the traditional period had for the most part only a quite abstract interest in how minerals came to be, rather than a curiosity about where and in what forms they were likely to be found.[49] For example,

[47] Stočes (1958), Vol. 1, p. 58. [48] See below, (*d*)(3).

[49] For a discussion of these theories, see Vol. 3, pp. 636–41. When hazarding a generalisation about the location of mines, they were as likely as not to be wildly mistaken. Even a Sung Ying-hsing, whom we shall discuss in a moment as the Ming author of the extremely important *Thien Kung Khai Wu* (*TKKW*) (The Exploitation of the Works of Nature), could confidently claim that gold and silver deposits, 'because of the earth's essence' (*khun yuan ching chhi* 坤元精氣), would 'generally' not be found within 300 li of one another, this being a clear indication of the intent of nature's creative force (*tsao wu chih ching i ta kho chien* 造物之精亦大可見). *TKKW*, ch. 14, p. 237; Sun & Sun (1966), pp. 241–2. This suggests that Sung had no idea that native gold almost always contains at least some silver or that some of north China's richest silver deposits occurred in gold quartz veins. Cf. below, Section (*e*)(2). Sung also seems to deny in the same discussion the existence of silver placers which, though rare, do exist.

to account for the absence of silver in Hopeh and Shantung, Sung Ying-hsing 宋應星 is content to attribute it to the coldness of the matter-energy (*chhi* 氣) and the thinness of the 'rock bones' (*shih ku po* 石骨薄) in these provinces.[50] Such explanations bring to mind Aristotle's similarly abstract kind of theorising that vaporous and smoky exhalations within the earth give rise to two categories of matter: metals and *fossiles* (homogeneous minerals) such as sulphur and certain other stones.[51]

Much of the lack of interest in explaining where and in what form mineral deposits appeared, and why, may have resulted from the stress by Chinese thinkers on *time* for explaining nature, and particularly as the 'essential parameter of mineral growth'.[52] The corollary of this emphasis was a relative neglect of *space*. The resulting theories, especially since their long time periods for the most part precluded checking against reality, provided little or no help to working miners.

Time, indeed great stretches of it, is of course crucial to modern geology and its explanations for the appearance of minerals. It is therefore important to recognise that the Chinese did develop in traditional times certain notions of geological time.[53] Nevertheless, it is equally true, at least from the perspective of modern science, that these cosmological theories 'followed a weary round of unsupported speculation', as did the many theories about the growth and mutual production of minerals in the earth.[54] To be sure, unsupported speculation also characterised most writing about nature in the West before the Renaissance. In both cultures, a very great imaginative leap was necessary before one could even entertain the idea that there could be another way of learning about nature.[55]

Greater familiarity with the experience of miners might have encouraged more empirical explanations of the mineral world. But this brings us to a second reason why mineralogical theories neglected topics having to do with mining. Very few of the literate who concerned themselves with these matters cared to follow the example of the learned +8th century pharmacologist, Chhen Tshang-chhi 陳藏器, and acquire some close, observational familiarity with mineral deposits and mining.[56] In fairness, we must also admit that such information would not have been very easy to come by, or to assimilate. China constituted a large area with a particularly wide variety of mineral deposits. With no existing body of literature presenting

50 *TKKW*, ch. 14, p. 235; Sun & Sun (1966), p. 238. 51 Multhauf (1958), p. 50. 52 Cf. Vol. 5, pt. 4, p. 231.
53 Vol. 2, pp. 485–7; Vol. 3, pp. 598–601. 54 Vol. 3, pp. 636–41.
55 Charlotte Furth nicely elucidates this perspective, contending that Chinese intellectuals with a classical education 'deemed speculative methods [unchecked by any kind of verification] to offer the only known way of talking about the universe at all, once men had departed from the authority of history or the certainties supplied by common sense empirical observation.' Such speculations, she argues, depended on aesthetic rather than rational appeal, with ordering principles that might be 'classificatory, numerological, rhetorical, or built out of richly suggestive analogical correspondences'. See Furth (1970), pp. 9–11. The first and last of these are particularly prominent in the pharmacological literature (including that on minerals), but all four are very well-represented, as can be seen for example in the first chapter of the first of the great pharmaceutical works, the *Shen Nung Pen-tshao Ching* (Classic of Pharmaceutics of the Heavenly Husbandman); see the translation in Unschuld (1986), pp. 19–20. For a thorough discussion of efforts to classify salts in traditional China, including 'non-scientific' categories such as place of origin and type of deposit, as well as connections with the salt monopoly, see Vogel (n.d.).
56 Schafer (1963), p. 251; Vol. 3, p. 650. Though this may well have been somewhat less true from Thang times on (Vol. 5, pt. 2, p. 281), China never produced a writer on mining who combined strong observational skills with a willingness to reject unsubstantiated theories.

basic, accurate information in a coherent and organised manner (to say nothing of adequate illustrations), any scholar trying to acquire an overview of the subject would have had to invest many years and a great deal of travel to observing mineral deposits *in situ*. Such physical rigours would hardly have appealed to the typical Chinese literatus.[57] Even with such a commitment, his difficulties would have been compounded by the secrecy that has surrounded mining in all cultures, not least in China. Allowing the existence of at least some willing informants, there were still communication gaps to be bridged, deriving from problems such as vocabulary, the inexperience of miners in verbalising what they knew, and the intuitive character of much of that knowledge.[58]

Thus, the theories that were produced to explain the presence of minerals were almost entirely divorced from close observation of the reality they purported to explain.[59] Only from time to time do we see the promise of something better, an insight that could have been built upon, but was not. For example, certain writers, when they talked of the growth of metals in the earth and their change into one another, had some concept of important changes (what we would recognise now as chemical changes) occurring in the constituents that made up the earth's crust.[60] Others, of whom the +11th-century Shen Kua 沈括 is an outstanding example, had fairly clear conceptions of erosion and sedimentary deposition.[61] In neither case, however, was the original insight followed up in a way that could be of any kind of practical use to working miners and prospectors. Even if the fascinating passage by Cheng Ssu-hsiao 鄭思肖 in his *So-nan Wen Chi* 所南文集 (Collected Writings of Cheng Ssu-hsiao), published around +1340,[62] can be taken to suggest deposition of minerals by waters through evaporation, the reference is at best oblique.[63] We may in temporal terms be only two centuries away from Agricola but in terms of ideas the two authors lie on opposite sides of a revolution in how one looked at the earth and its components. There can be little doubt that isolation from and lack of interest in prospecting and mining precluded the working out of theories firmly based in mineralogical realities and possessing real explanatory power. Closer connection

[57] As Ferdinand von Richthofen, the 'first real precursor of modern geology' and an indefatigable traveller through much of China, noted in the 1870s: 'the Chinese man of letters is sluggish and chronically loath to move rapidly . . . In his view, to go on foot is demeaning, and the occupation of geologist a direct surrender of all dignity in the eyes of the world.' Charlotte Furth, who cites this statement, notes that Ting Wen-chiang (V. K. Ting), the father of modern geology in China, used the same statement to lead off his introduction to the first issue of *Ti-chih hui-pao*, the first technical journal in geology to be written entirely in Chinese. Furth (1970), pp. 39–40. Precisely because he understood this, Ting strongly emphasised that his geology students engage in field work, more so even than was the case at many Western schools in the same period. *Ibid.*, pp. 48–9.

[58] Even a masterpiece such as Agricola's *De Re Metallica* displays significant limitations because the author's excellent contacts alone did not always permit him to penetrate the secrecy that surrounded mining practices or to overcome his own limitations as an 'outsider' (despite his years spent as a doctor to miners) rather than an experienced miner; Suhling (1977), p. 582.

[59] It should be noted that close observation was no infallible check on mistaken theory. For example, the belief in Europe that base metals in the ground could gradually be transmuted into more noble metals actually appeared to be supported by observations of the presence of noble metals within base metal deposits (e.g., silver in galena, the lead ore)! Dibner (1958), p. 21.

[60] Cf. Vol. 3, p. 637; Vol. 5, pt. 4, pp. 231–6. [61] Cf. Vol. 3, pp. 603–5. [62] Cf. Vol. 3, p. 650.

[63] The crucial words 'evaporate [the waters] and leave mineral deposits' had to be interpolated into the translation.

with mining reality would also have quickly revealed where certain ideas went wrong. For example, Chinese ideas on associations of various minerals or minerals and rocks, at least as they appear in the written documents that have come down to us, not infrequently combine inductive knowledge drawn from observation with arbitrary *yin-yang* 陰陽 theory. A good example is the gold/iron association which appears prominently as early as the *Shan Hai Ching*,[64] which notes for a number of mountains that iron can be found on their *yin* face and gold on their *yang* face. The association of gold and iron has a sound geological basis; that one can predict their regular appearance on specific sides of mountains, however, is a totally arbitrary and mistaken assumption.[65]

In propounding mineralogical theories, writers were also often misled by the Chinese affinity for analogical reasoning to introduce inappropriate anthropomophic and agricultural perspectives into their theories. Just as the Chinese classification of plants always emphasised how they could be put to use by humans,[66] so, too, there was a considerable anthropomorphic element of a different kind in their view of minerals. Minerals were supposedly born in the earth by means of the copulation of natural forces; they had male and female elements; native deposits of a mineral could serve as the 'mother' of further deposits; there exist 'embryos' out of which minerals grow; etc.[67] Such metaphors could be very misleading: Sung Ying-hsing 宋應星 seems to have had a mental picture of a growth of minerals in the ground that was very much 'agricultural'. He described tin ore as continuing to grow even after it had filled the empty space available to it underground, thus causing the collapse of hillsides (*thu chung sheng mai chhung wu chih shan thu tzu thui* 土中生脈充物致山土自頹.[68] Sung also explicitly noted that: 'Too frequent mining [of gold] . . . will exhaust the stock, and the yield is likely to be limited when a place has been worked over a period of years.'[69] What we seem to catch a glimpse of here is how the ideas of mineral growth in the earth[70] and lack of a clear line dividing organic and inorganic matter combined with anthropomorphic and agricultural ideas of relatively rapid growth to create in many Chinese minds a picture of rather speedy natural replacement of mined minerals.[71] Thus Sung also believed that coal

[64] For this work, see the following section.

[65] Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 266–7. Cf. Wagner (1993), p. 250, fn. 7. For further discussion of rock and mineral associations in traditional China, see (*f*)(4) below.

[66] Sun (1965), p. 406; Bray (1989), p. 4.

[67] For specific examples, cf. Vol. 3, pp. 636–41; Yen Chung-phing (*1957*), p. 53.

[68] *TKKW*, ch. 14, p. 240; Sun & Sun (1966), p. 251. Far to the west, in Yunnan, tin miners shared a belief in the growth of metals within the earth as well as their ability to metamorphose into something else. Thus, if a body of tin ore grew to fill a mountain and was not mined in good time, the ore would change back into ordinary rock; Su (*1942*), p. 16.

[69] *TKKW*, ch. 14, p. 234; Sun & Sun (1966), p. 236.

[70] An idea that was by no means totally absent in the thinking of miners, in China and elsewhere; Sivin (1986), p. 110.

[71] Interestingly, however, we have no evidence that the Chinese ever applied the theory of growth of minerals in the earth to the one kind of mineral deposit to which it best applies: bog iron. Indeed, neither Donald Wagner nor I have been able to find more than one reference of any kind to bog iron in the Chinese sources, that of Sung Ying-hsing in the *Thien Kung Khai Wu*, and even that reference is none too clear; *TKKW*, ch. 14, pp. 239 and 256; Sun & Sun (1966), pp. 246 and 248; Wagner (1993), p. 262.

was inexhaustible and that, if worked out coal mines were filled with earth, coal would reappear there *in twenty or thirty years*![72]

Lexicography is another area where the approach to minerals was largely divorced from considerations intrinsic to the minerals themselves. John Francis Davis, writing in the middle of the 19th century, quotes Rémusat to make the very important point that the basic categorisation of the mineral kingdom into precious stones (or 'jades' *yü* 玉) rocks (*shih* 石), earths (*thu* 土), salts (*lu shih* 鹵石) and metals (*chin* 金) arose not from 'a methodical or systematic arrangement contrived by naturalists, in order to classify the objects they wished to describe, but a mere distribution of written signs, brought together according to their orthography [i.e. what we now call their radicals], and classed by the makers of dictionaries, solely with a view to facilitating and expediting the search for them.'[73] Although Rémusat goes on to suggest that these groupings arrived at on orthographic grounds nevertheless 'could afford even to the vulgar . . . just notions of the natural affinities of things', such categorisations could hardly have been of any use to miners and may well have misled writers who took an interest in the mineral world. Furthermore, as remarked by Vogel, 'all the designations in the 'Literary Expositor' (*Erh Ya* 爾雅) dictionary referring to salt are based on passages in the classics. The same is true of its early +2nd century successor, the 'Analytical Dictionary of Characters' (*Shuo Wen Chieh Tzu* 說文解字).[74] Dictionaries did much to reinforce a 'knowledge' of minerals based on literary texts rather than empirical observation; even in the pharmaceutical works, the great majority of the many salt designations also had their origins in literary works.[75]

Finally, Chinese thought about minerals also suffered from a strong tendency toward what we might call theoretical sclerosis.[76] Much of that theory, especially mineral associations and the mutual influences of one mineral upon another, must have derived in part from empirical observations.[77] The idea that minerals grow in

[72] *TKKW*, ch. 11, pp. 202–3; Sun & Sun (1966), p. 205. Other Chinese were not quite so sure. In a meeting with officials from the Tsungli Yamen or Foreign Office in 1863, the American geologist Raphael Pumpelly discovered that the officials still believed that coal grew in abandoned mines. At the same time, they were opposed to extensive mining since that might exhaust the store of coal on which future generations would be dependent. When it was suggested that the two views were inconsistent, the officials got over the objection by saying that the rate of growth of new coal was unknown. See Pumpelly (1870), p. 287. This kind of thinking about the supposed growth of minerals was also shared by many even well-educated Greeks and Romans who observed the formation of stalagtites and the impregnation of wood by metallic salts and concluded that minerals were capable of organic growth and worked-out mines would revive themselves if left idle for a certain time. Cf. Healy (1978), p. 19; Rickard (1932), pp. 112, 579; Shepherd (1980), pp. 3–4. The same idea was to be found in Europe in the +17th and +18th centuries. J. R. Glauber, the German chemist and physician, wrote in the middle of the +17th century about the belief of miners that base metals gradually developed into more perfect ones such as silver and gold; thus, 'when the miners sometimes dig up an untimely ore, such as bismuth, cobalt, or zinc, and test it for silver without finding any, they say, we have come too soon . . .'; Weeks & Leicester (1968), p. 140. Cf. also Nef (1952), p. 431. Actually, even in the 19th century, the notion of the growth of minerals in the earth was still widely accepted in Europe; Dibner (1958), p. 21.

[73] Davis (1844), Vol. 3, p. 94. Of course, also grouped under these radicals were many characters that had no direct connection with mineral classification or mineralogy; see Vol. 3, p. 641.

[74] Vogel (n.d.), pp. 13, 15. [75] *Ibid.*, p. 22.

[76] For a suggestive discussion of this point as it relates to the pharmaceutical works (*pen-tshao* 本草), cf. Unschuld (1986), pp. 6–9.

[77] Cf. Vol. 5, pt. 4, p. 233.

the earth might have been stimulated by the dendritic forms sometimes taken by native gold and silver deposits.[78] Once generalisations or theories were committed to writing, however, they tended to aquire a force that inhibited further feedback from experience.[79] Not that progress toward greater understanding was impossible. For example, salts, because of their common properties, were gradually perceived to form a distinct group among the rocks and minerals.[80] But many ideas about minerals tended to remain quite fixed and, often enough, just plain wrong while mining experience and practical knowledge continued to develop.[81] Thus, the practical knowledge of the miners must often have been ahead, perhaps far ahead, of the theorising of the bookmen.[82] But we can never know how far, and in exactly what areas. Only occasionally do we have hints of what must have been a rich oral mining tradition. The *Kuan Tzu* 管子 text (dating from perhaps the late Chou or early Han) on the relation between the soil above and the minerals underground may be an example of a bit of that tradition that chanced to find its way into the written literature.[83] The remarkable excavations of ancient copper mines such as those at Jui-chhang 瑞昌 and at Thung-lü shan 銅綠山 also offer a particularly vivid example of unrecorded practical knowledge. How much of the sophisticated mining practices revealed by those excavations could we even guess at if we had to rely solely on pre-Han writings that have survived? Very little indeed.[84]

(3) Geographical and Administrative Writings

The first important geographical work in China[85] and the harbinger of what would become a voluminous corpus is the *Shan Hai Ching* 山海經 (*SHC*) (The Classic of the Mountains and Rivers). The information on minerals in the *SHC* as it exists today is found in what is the earliest core of the work, the first five chapters or the *Wu Tshang Shan Ching* 五藏山經 (The Five Storehouses Mountain Classic). These consist of materials that orginally may have been written as early as the beginning of the Warring States period (−5th century) or even somewhat earlier.[86] Their impressive

[78] Forbes (1956), p. 43. The same is true of native copper deposits.

[79] Vogel (n.d.), p. 27. The reluctance of later writers to modify or discard earlier interpretations is especially marked in the *pen-tshao* tradition where '[e]ach work in the main tradition takes over nearly the entire contents of the previous pen-ts'ao. New drugs and dissenting or supplementary commentaries are not inserted instead of but are added to the old, perhaps outdated statements.' Unschuld (1986), p. 28.

[80] Vogel (n.d.), p. 27.

[81] The association between magnetite and copper was one of the most commonly accepted in the Chinese literature. It was first referred to in the *Kuan Tzu* (*KT*) and still accepted by Wu Chhi-chün in the Chhing (Yen Chung-phing (*1957*), pp. 50–1). But the fact remains that there is no especially common association between magnetite and copper, as miners undoubtedly realised.

[82] Lest one assume that this was a phenomenon unique to China, it is well to recall that excessive reliance on earlier written accounts rather than observation of contemporary practice was not uncommon even among writers on technology in +18th century Europe; Harris (1976), p. 169.

[83] Amano (*1953*), pp. 236–7.

[84] The same applies to mining in ancient Greece and Rome, and to other early mining traditions as well.

[85] Excluding the very brief and often ambiguous 'Yü Kung' 禹貢 (Tribute of Yü) incorporated in the *Shu Ching* (Historical Classic; Legge (1865), pp. 92–155).

[86] Cf. Vol. 3, pp. 503ff.; Shimonaka (*1959–1962*), Vol. 5, p. 274; Yang Wen-heng (*1978*), p. 300; Loewe (1993), p. 359. (The Yang article is translated into English in Anon. (1983), pp. 258–69.)

inventory of some 89 metallic and non-metallic minerals as well as various kinds of 'jades', rocks and clays[87] compares very favourably with the approximately 70 stones and substances mentioned in the first lapidary in the West, the *De Lapidibus* of Theophrastus, which was written around −300.[88] These chapters thus testify to a keen awareness on the part of Warring States Chinese of the variety of useful minerals and materials available from the surface of the earth as well as from underground. They also give us some idea of how the Chinese were trying to make sense of the variety in the mineral world, including efforts to generalise about where minerals were to be found, which minerals tended to be found together,[89] the properties of minerals and rocks (hardness, colour, lustre, etc.). Unfortunately, beyond that, the work's laconic statements are of very limited usefulness. Even when it is indicated or suggested that a certain kind of mining was taking place in a given area, we are offered no data on the scope of mining activity. Moreover, the *SHC* tells us nothing at all about how mining was actually carried on at the time these materials were written down and it will therefore be of little use to us here.[90]

The geographical works that followed the *SHC* are, for the most part, disappointing as sources for information on mining and especially mining technology. By far the majority were written either directly under government sponsorship and/or by officials and were concerned mainly with administrative geography.[91] Insofar as they concerned themselves with mining (and that was to a very limited degree), they tended to focus on the revenue or product to be obtained by the government from mining rather than on the mining activity itself.[92] Hence they sometimes provide us with extensive inventories of mineral deposits but seldom tell us much if anything about the nature of those deposits. Even great private works such as Ku Yen-wu's *Thien Hsia Chün Kuo Li Ping Shu* 天下郡國利病書 (The Characteristics of Each Province in the Empire) or Ku Tsu-yü's *Tu Shih Fang Yü Chi Yao* 讀史方輿紀要 (Essentials of Geography for the Reading of History)[93] have remarkably little to say about mining.

A significantly richer source among 'geographical' writings is the vast body of local histories ([*ti*] *fang chih* [地]方志) that deal with individual provinces, prefectures or districts (counties). Again, the percentage of material on mining is extremely small but, given the thousands of local histories that survive,[94] that still amounts to

[87] Yang Wen-heng (*1978*), p. 300. [88] Vol. 3, p. 647. [89] Vol. 3, p. 674.

[90] The dating of this work is an extremely complicated question in itself, one that has often been rather cavalierly ignored by scholars interested in other things; see Wagner (1993), pp. 247–50, which summarises and accepts the conclusions of Meng Wen-thung (*1981*). Note that Meng's book does not appear on p. 366 of the very useful discussion of the work by Riccardo Fracasso in Loewe (1993), pp. 357–67.

[91] For example, the geographical chapters in the standard histories and in the various *Hui-Yao* 會要 (Important Documents) collections (see Wilkinson (1973), pp. 140–1) as well as the comprehensive geographical works, starting with the *Yuan-ho Chun Hsien Chih* 元和郡縣志 of the Thang and culminating in the great *I Thung Chih* 一統志 (Comprehensive Geographical Monographs) of the Ming and Chhing periods (Wilkinson (1973), pp. 112–14). Chang Hung-chao (*1954*) is an indispensable entrée into these materials.

[92] This was true even in the case of the imperial sponsored translation of Agricola's great classic work on mining and metallurgy, the *De Re Metallica*, at the end of the Ming. See (*c*)(5) below and Vogel (1991c), p. 92.

[93] Both written in the middle of the +17th century.

[94] Wilkinson (1973, p. 114) says some 7,500 of them, with about 110,000 chapters.

a great deal of material, much of it not available in any other sources. Until now, the great problem here has been finding those many bits and pieces. For the most part, we have had to depend on the dogged combing of these works by our Chinese colleagues, following up scattered references in their articles. Harbingers of better things to come have been works like the two-volume collection of citations dealing with Chhing mining[95] which, in addition to drawing on standard administrative sources (discussed below), also includes at least some citations from the local histories, and the astonishing collection of more than 500 pages of citations solely from the local histories and specifically dealing with coal mining![96] As future compilations of this sort appear, we shall be able to tell the story of mining in China in far greater detail than is possible today.

Nevertheless, our efforts will always be hampered by the disinclination of the writers of most of our materials, namely, government officials, to delve very deeply into the actual practice of mining.[97] They had many reasons not to. Mines tended to be inaccessable, making travel to them difficult at best, dangerous at worst. The 'rough and ready' character of the miners and especially of those who ran the mines, together with their determination to keep secret most of what they were engaged in, could add a further element of danger for officials who attempted to investigate mines too closely. The low status of mining and miners, together with the terrible living and working conditions that tended to prevail at most large mining operations made direct contact with miners highly distasteful to most officials. As an anonymous Western writer in the late 19th century commented, 'the Chinese Mandarinate who have studied modern methods have been unable to impart their learning to the workmen or indeed to take part in metallurgical work without losing rank [status?].'[98]

Too close an association with mines and miners could even be counterproductive to their main purpose insofar as it acquainted the officials with the many problems that could make it difficult or impossible for the mines to meet their tax obligations. A good example was the ever-recurring problem of quotas, the yearly tax amounts the government required to be paid by a mine, regardless of its level of production. For many mines, it was virtually inevitable that meeting these quotas would become a problem. As Hu Ching 胡涇, the Investigating Censor for Yunnan, memorialised in +1473: 'When the mining began, the shafts were shallow and the ore abundant. It was easy to fulfil the quotas . . . Now, with [the need for] deeper shafts, profits from the mines have shrunk. The [*wei-ping* 衛兵] soldiers assigned to mining are dying from the poisonous atmosphere of the mines . . . Some of them must pawn their wives and sell their children to make their quotas. In the worst cases, they run away to save their lives and form gangs of bandits.'[99]

[95] Anon. (*1983*). [96] Chhi Shou-hua & Chung Hsiao-chung (*1990*).

[97] For no government in China can one say, as Pamela Long says for +16th century Europe: 'Clearly the active promotion of mining and metallurgy and the encouragement of technical authorship went hand in hand.' Long (1991), p. 330.

[98] Anon (1892), p. 97.

[99] *Hsu Wen Hsien Thung Khao*, Cheng-chhüeh 6, cited in Chhen Lü-fan *et al.* (*1980*), p. 19. The attitudes of the government and its officials will be further discussed in Section (*l*) below.

The result was that, except in times of crisis, officials tended to ignore the actual conditions of the mines in their areas of responsibility and instead confined their attention to questions of revenue. Nevertheless, scattered in the vast corpus of standard histories, collections of edicts and memorials as well as the collected works of officials, administrative encyclopedias, statute books and other bureaucratic writings, there are many bits and pieces of useful information dealing with mining technology. On occasion, one also finds more substantial treatments.

(i) *The* Tien-nan Khuang-Chhang Thu Lueh, *or* *'An Illustrated Account of the Mines and Smelters of Yunnan'*[100]

The single most useful account of mining practice by an official in traditional times is Wu Chhi-chün's *An Illustrated Account of the Mines and Smelters of Yunnan*, compiled between 1843 and 1845 when Wu was governor of Yunnan.[101] In large part a collection of texts from various sources, it includes an extensive discussion of copper and silver mining and smelting techniques as practised in +18th and early 19th century Yunnan. Even here, however, the basic perspective is administrative and the assembling of information an official would need to supervise mining effectively.[102]

Wu was born in +1789 into a prominent official family and, in 1817, earned the top ranking among those who passed the *chin-shih* 近士 examination. With that kind of start, we are not surprised to find that he was able to enjoy a classically successful official career, beginning with appointment as a compiler in the Han-lin Academy 翰林院, passing on to education posts in Hupeh and Kiangsi, and a period as vice-president of the Board of War, and finally culminating in his appointment as governor or governor-general of several provinces, including Hunan, Hupeh, Kweichow, Fukien, Shansi and, finally, Yunnan, where he wrote his *Illustrated Account*.[103]

In the best Chinese tradition, Wu was as accomplished a scholar as an official. He is actually best known for another work, the 'Treatise on [the Achievement of Consistency among] the Names, Facts, and Illustrations of Plants' (*Chih Wu Ming Shih Thu Khao* 植物名實圖考)[104] on which he worked for over 20 years and which was not published until 1848, the year after his death. It is clear that Wu relied greatly on careful personal observation when writing this work. He was not reluctant to speak with ordinary peasants in order to be sure he had his facts straight.[105] It is less clear how extensively he relied on personal observations for the material in his *Illustrated*

[100] Wu Chhi-chün (*1845*).

[101] The illustrations were provided by Hsu Chin-sheng 徐金生 who, at that time, was prefect of Tung-chhuan 東川 prefecture, the copper production centre in northeastern Yunnan.

[102] Sun (1965), p. 400. A vast amount was written about mining in Yunnan during the Chhing in most of which, to be sure, the technology itself plays only a minor if any rôle. For an excellent introduction to this literature, see Vogel (1987a), Appendix A.

[103] Sun (1965), pp. 395–6; Unschuld (1986), p. 255.

[104] This translation of the title is Unschuld's (1986, p. 255).

[105] Sun (1965), pp. 396–9.

Table 4. *Contents of the* Tien-nan Khuang-Chhang Thü Lueh

Section	Pages	Content
Yun-nan Khuang-Chhang Kung-Chhi Thu Lueh	1a–11b	Illustrations of mining and smelting operations and the tools used
Part 1 (*shang*)	1a–b	Introductory remarks
	2a–b	Prospecting for ores
	3a–b	Opening a mine
	4a–5a	Mining tools
	6a–7a	Differentiation of ores
	8a–10b	Furnaces and tools for refining and smelting copper and silver
	11a–b	Provisions and necessities for mine personnel
	12a–17b	The labour force
	18a–20a	Control of the labour force
	21a–b	Mine disasters
	22a–24b	Beliefs and rituals of the miners
	25a–27b	Excerpt from *TKKW* on silver, copper and lead
	28a–32b	Excerpt from the *Khuang Chhang Tshai Lien Phien* 礦廠採煉篇 by Wang Sung 王崧
	33a–37a	Excerpt from the *Tshai Thung Lien Thung Chi* 採銅煉銅記 by Ni Shen-shu 倪慎樞
	38a–50b	Excerpt of the 'Tzu Hsun Ko Chhang Tui' 諮詢各廠對 section of the *Thung Cheng Chhüan Shu* 銅政全書
Part 2 (*hsia*)	1a–15b	Names, locations and output of copper mines
	16a–20b	Names, locations and output of silver mines
	21a–25b	Names, locations and output of gold, tin, lead and iron mines
	26a–28b	Government appropriations for running the mines
	29a–33a	Salaries and wages
	34a–35a	Evaluation of officials in charge of the mines
	36a–58a	Transport routes and stages
	59a–62b	Transport boats and regulations governing their use
	63a–64b	Rules on metal wastage and extra weight allowed
	65a–66a	Ways of economising on the entire operation
	67a–70a	Coinage
	71a–76b	Purchase of Yunnan copper by other provincial governments
	77a–100a	Memorial by Wang Ta-yueh 王大岳, financial commissioner of Yunnan in 1766, on advantages and shortcomings of the copper administration of his time (*Thung Cheng Li Ping Zhuang* 銅政利病狀)
Tien-nan Khuang-Chhang Yü Chheng Thu Lueh	1a–24a	Maps of the administative divisions of Yunnan with geographical features and major mines indicated

Sun (1965), pp. 86–7, with characters added and some changes in the descriptions and page numbers given there.

Account, but he does not seem to have been the kind of person who could have settled simply for the written information provided by others.[106]

The *Illustrated Account*, as a kind of administrative handbook, is divided into two parts: the first deals with the technical side of mining, with mining labour, and with miners' rituals and superstitions; the second part, much the larger of the two, deals in considerable detail with more narrow administrative concerns such as the location and output of mines, government appropriations for mining, transportation of the refined metals, and coinage (Table 4).[107] Also included are illustrations pertaining to the technology of mining, and a series of maps, mostly of prefectures (*fu* 府), with the main mining sites indicated. The *Illustrated Account* has in recent times come to be recognised as an indispensable source of information on metal mining technology as it existed in at least one area of mid-19th century China. On the other hand, this was a work without great scholarly pretensions, and was researched and compiled quite rapidly.[108] It thus falls far short in scope, details and systematic treatment when compared with the great mining works that begin to appear in Europe with the Renaissance.

(4) Mining in the *Thien Kung Khai Wu*, or 'The Exploitation of the Works of Nature'

The major pre-Chhing work to attempt a fairly detailed overview of mining in China, together with some extended discussion of mining techniques, is Sung Ying-hsing's *Thien Kung Khai Wu* (*TKKW*) or 'The Exploitation of the Works of Nature', which appeared in +1637.[109] Sung's work goes far beyond mere categorisation and identification of minerals and actually deals with ore deposits and how minerals are found, how they are mined, and how they are treated (roasting, smelting, refining etc.) after they have been mined. There are also many illustrations of the processes. It is therefore extremely valuable as a source on late Ming mining and related technologies. At the same time, it suffers from a number of limitations that frequently make it less than fully reliable.

Sung had, to be sure, a general and often at least partially first-hand knowledge of virtually all the productive technologies of his day.[110] If his knowledge was vast, however, it was also sometimes quite superficial and even incorrect. He admitted as much himself.[111] This certainly applies to his knowledge of mining, and we shall

[106] Is he perhaps referring to himself in the following statement: 'Only those who have spent considerable time at mining sites are able to distinguish various kinds of veins. Therefore, I have recorded [the information on] veins.'? Wu Chhi-chün (*1845*), ch. 1, p. 2a.

[107] For a translation of the administrative sections of this work into French, see Garnier (1873), Vol. 2, pp. 173–264.

[108] Sun (1965), p. 399.

[109] For a discussion supporting this translation of the difficult title, cf. Yabu'uchi (*1969*), pp. 362–4. See also Li Chung-chün (*1984*), p. 72.

[110] *TKKW* is unique among premodern Chinese works in its scope; Yabu'uchi (*1969*), p. 361.

[111] *TKKW*, *hsu*, p. 1; Sun & Sun (1966), p. xiv.

frequently have cause in the following pages to qualify what Sung has to tell us. A major problem is that Sung, a native of Kiangsi, never had the opportunity to travel to most of even the major mining areas of China.[112] To be sure, Kiangsi was a scene of extensive and varied mining, but by no means could it serve as a microcosm of all Chinese mining. Sung therefore could have only an incomplete appreciation of the extreme variety of mining conditions and practices throughout the empire.[113] Whatever eyewitness information he was able to obtain about these other areas seems to have depended on informants of very unequal reliability, and of whom we know nothing specific.

Sung did, however, make good use of Kiangsi's long and varied mining tradition, learning a good deal about certain practices by observing mining at close hand. He probably also had access to information from Kiangsi mining specialists many of whom worked in neighbouring provinces.[114] Up to a point, this direct or almost direct information was a great advantage. But Sung often overgeneralised on the basis of what was still a rather narrow segment of Chinese mining practice. A good example is his association of coal exclusively with barren terrains.[115]

Moreover, while capable of admirable scepticism regarding certain things he was told – even to the point of sometimes rejecting information that could well have been true,[116] he could also be gullible, accepting as we noted above the relatively rapid growth of minerals in the earth, or the idea that jade could originally be as soft as cotton wool.[117]

Perhaps the major reason for the limitations of the *TKKW* is that Sung Ying-hsing 宋應星 lacked the motivation to provide the kind of precise and detailed explanations whose absence we so often regret in this work. As Yabu'uchi Kiyoshi has stressed, Sung was not writing his work for people with specialised knowledge of the technologies.[118] Sung makes clear in his preface that, though his work will be ignored by 'ambitious scholars', it is indeed meant for scholars and pampered members of the élite who typically have little or no knowledge of what it discusses.[119]

[112] Yabu'uchi thinks that Sung was 'rather well travelled' but admits there is no evidence to substantiate this; Yabu'uchi (*1969*), p. 371.

[113] The same criticism has been leveled at Agricola's *De Re Metallica* (see the following section) which dealt much more satisfactorily with +16th century mining in Saxony and Bohemia, where he was born and spent most of his life, than with other central European mining centres; Suhling (1977), p. 582.

[114] Sun & Sun (1966), p. ix. [115] Cf. section (*f*) below.

[116] For example, his disinclination to believe that small bits of gold could be obtained by washing the droppings of geese that swam in gold-bearing waters; cf. Section (*g*) below.

[117] *TKKW*, ch. 18, p. 307; Sun & Sun (1966), p. 303. The two attitudes can sometimes exist side by side: 'The baseless conjectures and annotations of the magicians' and pharmacologists' books are indeed very objectionable. The essence of the earth is generally so distributed that gold and silver are not found within 300 *li* of each other, which is an indication of the principles of Nature.' *TKKW*, ch. 11, p. 237, trans. Sun & Sun (1966), p. 241, slightly modified.

[118] Yabu'uchi (*1969*), p. 366. Yabu'uchi does suggest later in his discussion (p. 369) that Sung did perhaps to some extent see his work as a technical handbook. That may be, but neither the text nor the illustrations seem to me to provide much evidence that this consideration had any real importance for him. Primarily, the *TKKW* was a work of 'popularisation' directed at a very narrow audience.

[119] *TKKW*, Preface, p. 1; Sun & Sun (1966), pp. xiii–iv.

(5) Agricola in China

In +1556, the Basel publisher Froben brought out an elaborately illustrated, 586 folio page volume entitled *De Re Metallica*. Its author, whose German name of Georg Bauer had been latinised into Georgius Agricola during his school days, had died the previous year at the age of 62. He had devoted a large part of some 20 years to the writing of *De Re Metallica*.[120] In the two centuries following its publication, this work would pass through some ten editions, including four in Latin and three in German, clear testimony to the respect in which it was held.[121]

Agricola may have accepted some of the ideas of Aristotle on minerals and their changes in the earth (while completely rejecting the Biblical, alchemical and astrological views so prevalent in his day),[122] but a mere glance at his exposition of ore deposits[123] immediately makes clear that nothing in earlier writings in the West or in China can approach the careful observation, systematic exposition and analysis, and brilliant insight of this work.[124] In particular, as the Hoovers point out, Agricola announced for the first time and elaborated on two principles that are today still fundamental to the theory of ore deposits: (1) the origination of ore channels in pre-existing rocks; and (2) the deposition of ores from solutions circulating in those channels.[125]

Agricola's *De Re Metallica* was one of perhaps as many as 7,000 Western books dealing not only with religion and philosophy but also with the full range of Renaissance science and technology that the Jesuit Nicholas Trigault brought with him on his second trip to China in +1618. It drew the attention of Ming officials who imagined it might serve to promote an overhauling of Chinese mining practice. The hope was that the resulting rise in output would enable the government to derive greater tax receipts from mining, thereby bolstering a very straitened central treasury. An imperial order was issued to produce a Chinese version of the work and this was completed under the direction of the German Jesuit Adam Schall von Bell, whereupon it was further ordered that copies be sent out to mining

[120] Actually, the idea of the work had been in his mind for almost 30 years, since +1527. For easily accessible background on Agricola, see the introductory material in the liberally annotated first English translation of *De Re Metallica* by Herbert Clark Hoover and Lou Henry Hoover (Hoover & Hoover (1912)); Bern Dibner (1958), which provides introductory material and a summary of each of the twelve 'books' that make up the work, together with selected illustrations; Golas (1995a). There is a large and growing literature on Agricola, most of it in German. For works up to the early 1970s, see Prescher *et al.* (1974), pp. 837–45 and Michaëlis *et al.* (1971). For more recent work, see the yearly bibliographies in the German mining history journal, *Der Anschnitt*.

[121] This despite the fact that much of the technology described in *De Re Metallica*, including firesetting, was already on its way out even as the book was being published. This raises the interesting question of why newer, more up-to-date textbooks do not appear in Europe until the +18th century (though there were several mining dictionaries produced in the late +17th century). I am indebted to Graham Hollister-Short for these points. See also Long (1991, p. 328): '... the great age of mining literature was over by the end of the 16th century.'

[122] Hoover & Hoover (1912), p. 46. [123] *Ibid.*, book III.

[124] It should be noted that Agricola was greatly indebted to Biringuccio's *Pirotechnia*, first published in +1540, from which he copied '*in extenso*' for certain sections of his own work, though even here he 'usually added a superior illustration and often provided valuable additonal details'; Smith & Gnudi (1959), p. xvii.

[125] Hoover & Hoover (1912), p. 52.

installations.[126] Unfortunately, we have no further information on the project. The whole endeavour got caught up in the collapse of the Ming in +1644, and apparently no copies of the translation have survived. Agricola seems to have had no influence on China's mining practice and the whole episode thus represents mainly a fascinating historical might-have-been.[127]

(6) The Western Perspective

Mining opportunities drew many Westerners to China beginning in the second half of the 19th century. With their training and experience in modern mining methods, they were able to view the native methods in China from a radically different perspective. Happily, they not only viewed but also wrote, often prolifically.[128] This would have been a very different study had I not been able to draw on the accounts of people like von Richthofen, Hoover, T. T. Read, Junghann, Tegengren, Torgasheff, Slessor and many others whose names will appear often in the following pages. Like all of us, they were not without their prejudices, and their writings must be used with care.[129] Above all, they were mainly mining men, not historians. They often give us precious descriptions of what they saw in the final decades of the last century or the early part of this century. But in many cases, what they saw was an industry in decline compared to what they would have seen a century or two earlier.[130] It has been my job – and often not an easy one – to try to determine the extent to which what they saw reflected earlier mining practices and the earlier mining industry.[131]

[126] The Chinese version was entitled 'Exhaustive Investigations of (the Contents of) the Earth' (*Khun Yü Ko Chih* 坤輿格致) though Agricola's work is most commonly known today in China as the 'Treatise on Metallurgy' (*Lun Yeh Chin* 論冶金); Ho Ping-chang (*1984*), p. 456.

[127] On this episode, see Pan, Vogel & Theisen-Vogel (1989); Golas (1993); and Golas (1995).

[128] In this as in other ways, they contrast conspicuously with that earlier group of Westerners, the Jesuits in China during the +17th and +18th centuries, from whom Europe learned so much about the country and its people, but not its mining. The Jesuits had less interest in and contact with Chinese mining than even Chinese officials. See Vogel (1987a), Appendix A, agreeing with Commeaux (1970), p. 52.

[129] For an example of some of the influences that coloured their thinking, see Walsh (1943). Cf. also Brown (1923), p. 123.

[130] They themselves sometimes recognised this. Thus von Richthofen, commenting on the poverty of the owners of coal mines in the area around Tse-chou 澤州 in Shansi, also observes that the luxurious houses dating from an earlier era suggest a previously more flourishing industry, and argues that the introduction of foreign wrought iron played a rôle in the decline; von Richthofen (1875), pp. 17 and 19.

[131] Wagner (1993a), pp. 306–7.

(*d*) DEPOSITS

(1) The Definition of Ores

Minerals, of which there are more than 3,000,[1] are widely present in the rocks of the earth's crust. The term 'ore', however, is usually reserved for those rocks or minerals that can be exploited to economic advantage. Ore deposits typically contain a greater concentration of many of the same minerals found disseminated only in minute proportions in many rocks. Gold, for example, makes up a mere 5/1,000,000,000 of the earth's crust.[2] Copper, though one thousand times as common as gold, exists for the most part only as a micro-constitutent of rocks.[3] Fortunately for the development of mining, geological processes have sometimes brought together even extremely rare minerals into rich enough concentrations (deposits) so that they can be mined economically.[4]

In traditional times, the Chinese did not usually distinguish a separate class of rocks that could be considered ores. Ores were simply included promiscuously under the classification of 'rock' (*shih* 石). For example, in the +1596 *Pen Tshao Kang Mu*, ore minerals such as azurite (copper), malachite (copper), hematite (iron), magnetite (iron) and smithsonite (zinc) are all classified as 'rocks'.[5]

What constitutes in practice an 'ore', that is, a mineral deposit that can be exploited to economic advantage, has differed considerably at different times and in different places. Differences in the social and economic conditions in which mining takes place as well as in the mining technology itself determine whether it makes economic sense to mine a given deposit. For example, where labour costs were low, as in China or in ancient Greece and in the Roman empire, many ore deposits that would clearly be uneconomical today could be worked profitably.[6] On the other hand, ores that today would be considered rich had to be bypassed in earlier times because they could not be handled effectively with primitive mining and smelting techniques. In China, many iron ore deposits containing sulphur, even those with high percentages of iron, were not exploited because of the difficulty of completely separating out the sulphur.[7]

(2) Classification of Ore Deposits

How miners mine is very much conditioned by the characteristics of ore deposits. Some familiarity with these characteristics is therefore indispensable for understanding mining technology. Unfortunately, this can be an extremely complex topic.

1 Ho Yueh-chiao & Chu Fu-hsi (*1986*), p. 1. Only something less than 120 are, even today, in industrial use.

2 Anon. (*1978b*), p. 34, fn. 1. 3 Patterson (1971), pp. 291–2 and 294. 4 Smith (1967), p. 143.

5 Hsia Hsiang-jung *et al.* (*1980*), p. 221. What we call minerals, in modern Chinese *khuang-wu* 礦物, were referred to in traditional times simply as *chin-shih* 金石 'metals/rocks'; Hsia Hsiang-jung *et al.* (*1980*), p. 229.

6 Forbes (1963), p. 225; Mathieu (1924), p. 450; Read (1912); Read (1920). 7 Chhen Ping-fan (*1954*), p. 119.

Specialists are by no means universally agreed even on approaches to the subject, much less on conclusions. The following discussion, then, will be limited to a brief, relatively non-technical, overview of some basic notions on which we shall draw as we discuss the development of mining technology in China.

Most rocks and related minerals are believed to have originated in magma, the molten mass of rock-forming substances, volatiles (gases) and metals that exists below the earth's crust. In terms of raw material, there is considerable similarity between rocks and minerals, since both come from the same source, i.e. magma. Rock and minerals can be usefully distinguished, however, by noting that minerals are true 'compounds' as chemists use the word. That is, their constitutive elements (such as silicon, oxygen, aluminium, calcium, etc.) are combined in specific proportions to form a distinctive molecular structure that is reflected in a characteristic crystalline form and in other physical properties (lustre, cleavage, hardness, etc.).[8] Thus, every mineral has a precise chemical composition that can be expressed by a chemical formula.

Rocks are typically made up of one or more minerals, for the most part from the approximately 20 abundant minerals that constitute about 99 per cent of the earth's crust.[9] The proportions of the constitutive minerals in rocks are not fixed and actual rocks vary greatly in their composition. Thus, one can think of elements as building blocks that come together in precisely fixed ways to constitute minerals, which in turn are combined in a great variety of ways to form rocks, which in turn are the bulky and immensely varied building blocks of the earth's crust.[10]

As magma cools, different mineral components crystallise and separate out by a process called 'magmatic concentration' or 'magmatic segregation' (Fig. 5). Up to the point where the entire mass solidifies, these mineral crystals are accompanied by a residual liquid ('mother liquor') that is the primary source of ore minerals. Rocks formed directly from magma are called igneous rocks. By far the great majority of mineral deposits are directly related to those igneous rocks, called intrusive rocks, that have risen to force themselves into pre-existing rocks of the earth's crust, especially by squeezing their way into cracks and crevices.

(i) *Primary deposits*

Deposits formed by magmatic and/or hydrothermal processes (Fig. 6) are called primary deposits and, along with sedimentary and metamorphic deposits, are one of the three major classes of ore deposits.[11]

[8] These are discussed below in (*f*)(5). [9] Rosenfield (1965), p. 7.

[10] Sinkankas (1970), pp. 84–6; Forbes (1963), pp. 105–6.

[11] As suggested above, there is no universally accepted classification of ore deposits. Rastall (1923), pp. 106–7 discusses why there is never likely to be. I have chosen to follow in a general way the classifications given in Emmons *et al.* (1932), pp. 435ff. and Rastall (1923), p. 111 because they seem to provide enough detail for our purposes without being overwhelming to the non-specialist. It deserves pointing out, however, that this classification shortchanges the influence of the environment of deposition (host rock type, structure, depth, etc.) which is of course extremely important for the nature of the resulting deposit. For other schemes, see (in increasing order of complexity) Stočes & White (1935), p. xv; Pearl (1973), p. 258; Bateman (1950), pp. 363–4; and Lewis (1964), facing p. 274. This list is far from exhaustive. I would like to express here my special thanks to Willem Lodder of Amax Exploration, Inc. on whose considerable knowledge and suggested wordings I have drawn considerably in this section. Robert C. Armstrong of Echo Bay Mines also provided many helpful suggestions.

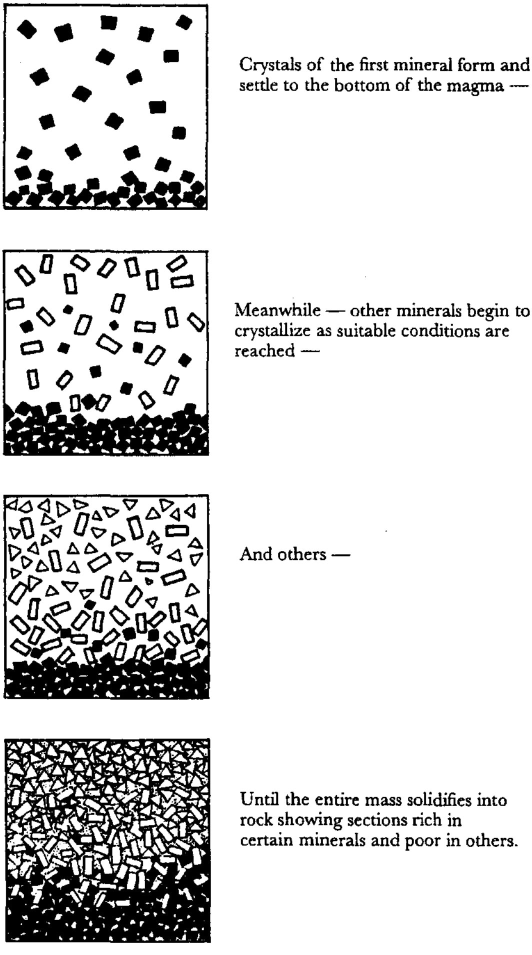


Fig. 5. Schematic representation of magmatic concentration. Crystals forming at different times result in rocks of widely different composition, though the original materials come from the same parent magma. From Sinkankas (1970), p. 142, fig. 64.

Primary deposits can be further divided into magmatic segregations, contact metamorphic deposits and mineral veins. Magmatic segregations or concentrations, as described above, form within the boundaries of intrusive igneous rock masses by the consolidation of magma. They can be an important source of valuable mineral concentrations such as nickel, chromite and magnetite. A special kind of magmatic concentration are the coarsely crystalline pegmatites. Pegmatites are formed during the normal sequence of crystallisation of volatile-rich magmas at

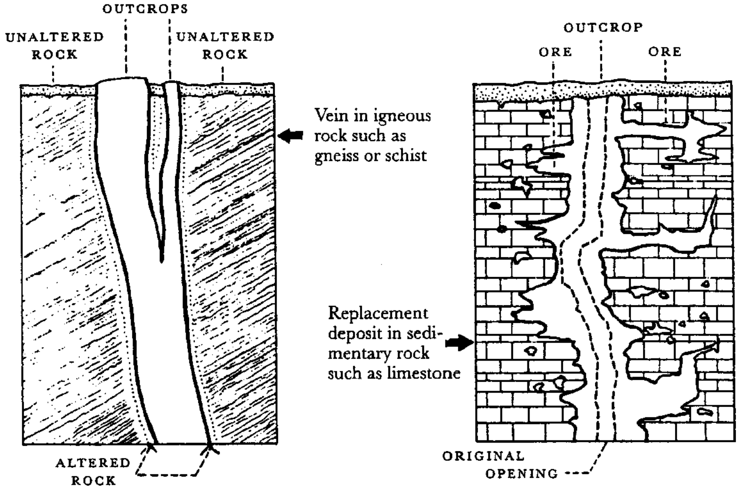


Fig. 6. Hydrothermal deposits. The two illustrations contrast the typical resistance of igneous rocks (left) to attack by pneumatolysis and hydrothermal processes with the greater susceptibility of sedimentary rock like limestone (right). Modified from Sinkankas (1970), p. 155, fig. 69.

that point when the residual fluid is sufficiently enriched with volatile materials to permit the formation of coarse-grained rocks. Pegmatites are major sources of feldspar (used in ceramics), mica and gems, and are sometimes a source of cassiterite, the main tin ore. Since pegmatite deposits, even fairly extensive ones, typically occur as 'scattered, relatively small lenses and pods', they are almost exclusively exploited in small-scale or artisanal mining operations.[12]

Contact metamorphic deposits are formed by transformation of invaded rock either directly by the intrusive rock or, often, by liquid or gaseous solutions associated with the invading rock. In the latter case, the hot solutions sometimes dissolve the invaded rock, with the new material slowly replacing the old 'atom for atom, very much as if one were to remove clay bricks from a wall, one at a time, while putting a metal brick in each vacancy thus created.'[13] The invaded rock may be an earlier igneous rock or a sedimentary rock such as limestone or calcareous shale, though significant changes typically occur only in sedimentary rocks.[14] China, with its ubiquitous limestone formations,[15] provides a propitious environment for this kind of deposit, which frequently contains tin, copper, iron and zinc ores and, less often, gold, silver and lead.[16]

[12] United Nations (1972), p. 32.
[13] Paul (1963), p. 6. Deposits formed when material from the invading solution is introduced into the invaded rock are often referred to as contact metasomatic deposits; Whitten & Brooks (1972), p. 288.
[14] Sinkankas (1970), p. 151. [15] Torgasheff (1930), p. 35. [16] Phan Chung-hsiang (*1951*), p. 139.

Mineral veins, the third type of primary deposit, are the most numerous and are often very valuable deposits. They consist of infillings of cracks and fissures at medium or shallow depths mainly by magmatic waters and gases, though descending surface or meteoric (atmospheric) waters may also play a rôle in their formation.[17] These waters and gases, in the form of alkaline solutions produced from their reaction with wall rocks, move through fissures, bedding planes and other openings, depositing minerals on the surrounding wall rock (cavity-filling deposits) and sometimes replacing that rock with mineral deposits (replacement deposits) (Fig. 6). Unlike most metamorphic deposits which do not follow well-defined fissures and are very irregular in shape, veins often have a tabular shape. The implied analogy with blood veins in the body is misleading; only a minority of veins, the kind often referred to as 'pipes', are tubular in shape. Veins are usually though not always steeply inclined or vertical; for some unknown reason, an inclination of about 70° is especially common.[18] Veins are a major source of metals such as gold, silver, copper, tin, lead, zinc, mercury and antimony. A single vein may produce more than one metal, either at the same level or because it changes its composition at different depths.[19] Except for gold-bearing (and some copper-bearing) veins, metals are usually present as sulphides or in association with sulphides, the implications of which we shall return to below.

(ii) *Secondary deposits*

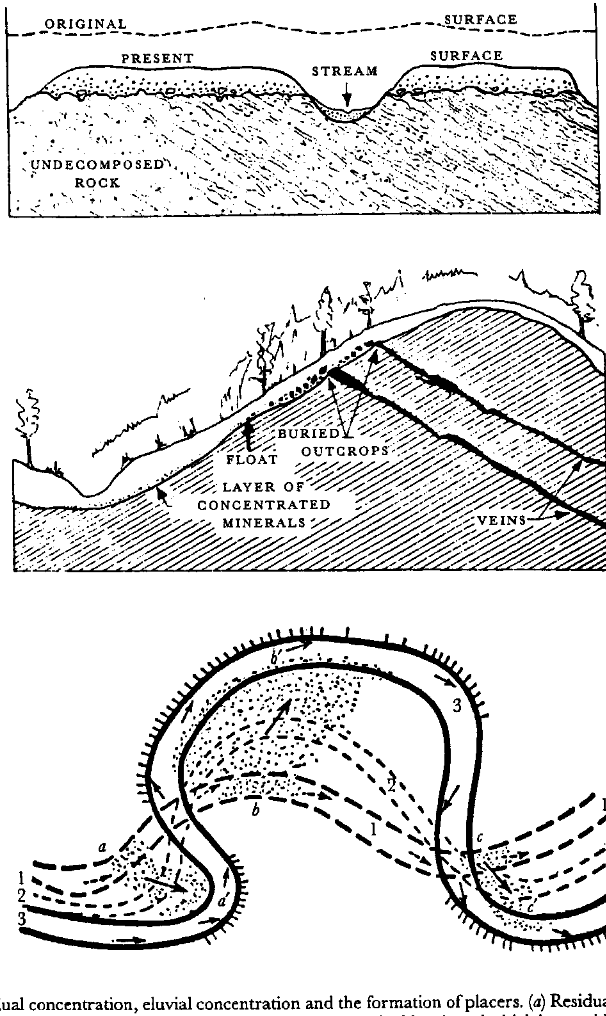
Secondary deposits, the second major category of deposits, derive from primary deposits that have undergone alteration through mechanical or chemical processes. When rocks are subjected to weathering, their constituent materials are often broken down and separated (erosion). This can occur through changes in temperature that create differential thermal expansion in the rock itself, through the expansion of water as it freezes in cracks, through plant growth in the rock, or through abrasion by moving solid particles. These constituents in turn can be transported from their orginal location by various forces such as running water, the wind, seepage, and downslope movement of mineral-containing soil (sedimentary deposition). This sometimes results in concentrations of minerals and thus the formation of deposits, including the very important placer deposits (Fig. 7). Alternatively, valueless materials

[17] The action of magmatic gases is called pneumatolysis while that of magmatic water is usually referred to as hydrothermal processes. The latter are further divided, according to the depth at which they occur, into hypothermal (deepest, with high pressure and heat), mesothermal and epithermal (shallowest, with low pressure and heat). For the ore minerals, gangue materials and chief metals associated with each, cf. Healy (1978), pp. 23–4 and Phan Chung-hsiang (*1951*), pp. 136–7. It should be noted that the distinction between pneumatolysis and hydrothermal processes is somewhat arbitrary since the two have often been at work simultaneously; Whitten & Brooks (1972), pp. 353–5; Bateman (1950), p. 301. Moreover, recent theories have been proposed that reject the notion of a magmatic origin for hydrothermal waters and argue instead that these waters actually come from host rocks that are intruded by an igneous mass that serves as a 'heat engine' sending the waters upward along zones of weakness until pressure and temperature decrease to a point where mineral precipitation can occur. (Robert C. Armstrong, personal communication.)

[18] Rastall (1923), pp. 72, 80. Horizontal veins are sometimes referred to as 'flat veins'.

[19] For example, copper veins may become lead veins at depth while lead veins at depth may become zinc veins. Emmons *et al.* (1932), p. 441. At Ko-chiu in Yunnan, miners originally sought lead and silver. At depth, however, tin appeared and rapidly increased until the mining eventually continued only for tin. Bain (1933), 173.

(a)



(b)

(c)

Fig. 7. Residual concentration, eluvial concentration and the formation of placers. (*a*) Residual concentration. The black dots in the undecomposed country rock represent a valuable mineral which is too widely disseminated for economical mining until mechanical or chemical weathering concentrates it in a layer between the topsoil and the unaltered rock below. From Sinkankas (1970), p. 169, fig. 75. (*b*) Eluvial concentration. The valuable mineral is concentrated by the downslope movement of soil. From Sinkankas (1970), p. 169, fig. 75. (*c*) The formation of river and stream placers. Three positions of a stream over time (moving from 1 through 2 to 3). Arrows in the stream indicate points where the current cuts out material from the banks of the stream. The remaining arrows indicate how the deposits thus formed extend laterally and downstream, from *a* to *a'*, etc. From Healy (1978), p. 32, fig. 8.

may be carried away, leaving valuable concentrations behind. This happens often with gold, which is not readily soluble.[20] Deposits of tin, gypsum, iron ores, common salt, potash salts, phosphate rocks, clays and many other minerals and materials can be formed in this way.[21]

In addition to these mechanical forms of weathering, rocks may also undergo chemical weathering caused by the solvent action of surface waters or organic acids, with soluble substances (silica, carbonates, sulphates, chlorides) being carried down into the ground and often away from their original location. This chemical precipitation can produce deposits of certain iron ores, salt, bauxite, phosphate rock, etc.[22]

The operation of weathering processes over a long period often produces a distinctive pattern of ore deposition in mineral veins. It is best understood, and perhaps most important, in copper vein deposits (Fig. 8). The primary ores of copper veins are the sulphides bornite and chalcopyrite. These sulphides are very unstable and can be easily oxidised by surface water. The upper part of the vein thus becomes oxidised and more or less leached of its soluble copper minerals. Often, it is left with a 'cap', the gossan (*thieh mao* 鐵帽), which consists of iron ore (especially the iron sulphide, pyrite, which is frequently present in copper veins) that has undergone oxidation and become the iron oxide limonite.[23] The soluble minerals, in a process called supergene or secondary enrichment, collect either in a zone above the water table as native metals, carbonates, silicates and oxides, or in a zone below the water table as secondary sulphides. This is what happened, for example, at the 'Immortal's Seat' (*hsien-jen tso* 仙人坐) deposit at Thung-lü shan 銅綠山 (Fig. 8).[24]

The oxide zone, including the zone of enriched oxides that not infrequently extended to a depth of 50 m or more from the surface, was especially accessible to traditional mining and smelting techniques. This led to the opening up of many important mining districts.[25] However, prospectors probably often missed potentially rich deposits because the oxide ore at or close to the surface had been so

[20] Emmons *et al.* (1932), pp. 4–5.

[21] At Ko-chiu, the tin placer deposits owed little to concentration by running water. Instead, they were created when the limestone country rock disintegrated *in situ* over long periods of time, allowing the cassiterite to settle to the bottom of sinks where nearly all the Ko-chiu placers are found; Draper (1931), pp. 183 and 244.

[22] As noted above in Section (*c*), some Chinese such as Shen Kua of the Sung had fairly clear conceptions of erosion and sedimentary deposition. There do not seem to be any surviving writings, however, that connect those processes with the formation of mineral deposits. Of course, it is likely that many a prospector or miner had at least an intuitive understanding of what was happening.

[23] For an especially good discussion of limonite gossans, cf. Phan Chung-hsiang (*1951*), pp. 142–3. These 'iron caps' with their distinctive appearance and colours, were an important clue for traditional prospectors; they undoubtedly even came to be able to distinguish the yellow-brown caps that often indicated a galena deposit from the dark brown or palm-tree brown that was frequently associated with chalcopyrite deposits, or the very regular, squarish holes that suggested pyrites from the tubular holes that often indicated arsenopyrite. Anon. (*1971*), pp. 95–6. Cf. also Wertime & Wertime (1982), p. 162 and below, (*f*)(4).

[24] An interesting example of these processes at work is encountered at the Thung-lü shan excavations. In the 2000+ years since the early excavations there, feathery or fibrous deposits of natural copper and powdery deposits of cuprite had precipitated out of the fill materials onto the timber supports left in place when worked out areas were filled in and abandoned. Yang Yung-kuang *et al.* (*1980–1981*), p. 81 (part 2).

[25] The famous Thung-chhuan copper deposits in northeastern Yunnan had a massive oxidation zone 600 m in depth! Hsia Hsiang-jung *et al.* (*1980*), p. 259.

(a)

(b)

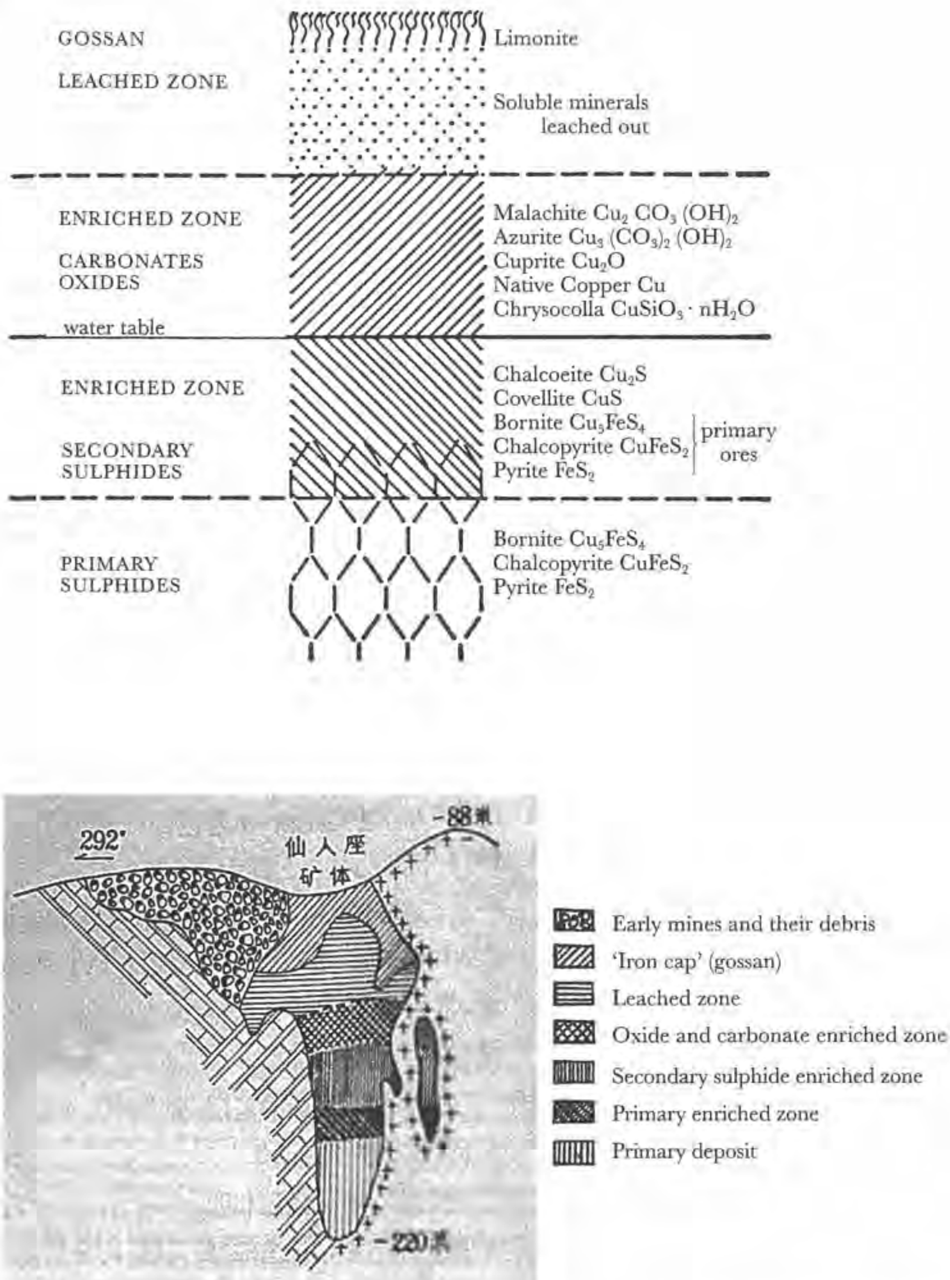


Fig. 8. Secondary enrichment in theory and as found at Thung-lü shan 銅綠山. (*a*) Schematic rendering of the effects of secondary enrichment on a copper vein or massive deposit. Rosenfield (1965), p. 134, fig. 27. (*b*) The 'Immortal's Seat' (*hsien-jen tso* 仙人坐) deposit at Thung-lü shan. Yang Yung-kuan *et al.* (*1980–1981*), p. 86; Hsia Nai & Yin Wei-chang (*1982*), p. 2.

extensively leached of its minerals that there was little or no hint of the rich deposits at greater depths.[26] If, on the other hand, prospectors or miners did discover the zone of enrichment, that could also lead to wildly exaggerated estimates of the grade of the deposit as a whole. In the case of the complicated silver ores, which were often difficult to process after mining, supergene enrichment could misleadingly encourage miners in another way. The leaching out of sulphides, lead and antimony at the shallow depths could produce a 'docile' or easy-to-treat oxide ore that would then give way to the typically difficult sulphide ores at depth.[27] Chinese miners, with no modern chemical understanding, could of course have no idea that this was a predictable phenomenon (at least insofar as anything in ore deposits is predictable!)

(iii) *Metamorphic deposits*[28]

Both primary and secondary deposits may undergo metamorphosis as a result of forces that cause them to sink to sufficient depth that the weight of the overlying formations subjects them to powerful forces of stress (pressure) and heat. The resultant chemical reactions give rise to metamorphic rocks such as schist, marble and quartzite, and to metamorphic ore deposits. Alternatively, magmatic intrusion into existing igneous or sedimentary rocks can give rise to extensive metamorphosis.

Metamorphic deposits, though often low grade, can sometimes be quite important. Anthracite coal is one important product of metamorphism. Other significant metamorphic deposits include graphite, asbestos, talc, soapstone, abrasives (such as garnets), roofing slates, ceramic materials (such as kaolinite) and certain gemstones (such as zircons), as well as sulphide deposits of nickel, copper, lead, zinc and tungsten (the last not important in China until this century).

In north China, apart from some very old pre-Cambrian schist, gneiss and granite, metamorphism has generally been rather limited. In south China, however, it has produced, mainly by means of igneous intrusions, many important deposits.[29]

(3) Chinese Miners' Understanding of Ore Deposits

The above outline of ore deposits, like all modern classifications, considers not only the form and mineral content of the deposits but also, most importantly, how the deposits came to be. Traditional miners, in China as elsewhere, had nothing comparable to modern geological understanding to draw on and were therefore unable to consider genesis when looking for deposits or trying to assess the workability of

[26] Phan Chung-hsiang (*1951*).

[27] Paul (1963), p. 100. The problem was compounded by the fact that silver-containing outcrops were very often richer at shallow depths, tending to thin out at greater depths; Phan Chung-hsiang (*1951*), p. 142.

[28] These should not to be confused with the contact metamorphic primary deposits discussed above.

[29] Willis (1908); Bain (1933), pp. 150–1.

deposits they had discovered. The Chinese miners simply attributed the appearance of deposits implicitly to chance[30] or explicitly to the generosity of the spirits who constantly had to be persuaded to be generous, and then thanked when they had been. At the Ko-chiu 箇舊 tin mines, for example, the presence of ore deposits was credited exclusively to the Dragon King of Ore Deposits (*Khuang Mai Lung Wang* 礦脈龍王) or the God of Wealth (*Tshai Shen* 財神).[31] Still, miners could not help but develop at least some intuitive understanding of the larger geological structure of those areas in which considerable mining was carried on. For example, Tegengren found it 'conspicuous and remarkable' that the Chinese in southern Shansi had established native iron mines wherever the iron-bearing formation was workable, even when it was covered by several metres of loess, an indication that 'the ancient miners had some rough idea of the geological structure of the region.'[32]

But premodern miners in China, like their counterparts elsewhere, probably paid most attention especially to the form of the deposit (its shape and position) and the nature of its mineral content when attempting to formulate some kinds of general rules to decide which deposits might be worth working. Since the form of the deposit was the more directly observable of the two, it tended to serve as the basis for classifications of deposits.[33]

Wu Chhi-chün and Ni Shen-shu together provide us with an example, albeit rather late, in the relatively detailed classification of copper ores constructed by miners in Yunnan (Table 5 and Fig. 9).[34] The almost exclusive emphasis on the form of the deposits is very clear, as is the fact that the veins are described from the surface down, as they naturally reveal themselves, rather than from within the earth up to the surface which is the main perspective of modern genetic classifications, especially of the kinds of vein deposits that are emphasised here. Moreover, Chinese miners seem not to have developed any clear sense of contact deposits. This is not surprising since the recognition of such deposits relies not only on a genetic perspective but also on the rôle of chemical reactions in the formation of these deposits.

(4) China's Ore Deposits

(i) *Overview*

We have already noted above (Section (*a*)(2)(i)) that the ore deposits discovered and exploited by the Chinese in traditional times were widespread and very varied. As the editors of the most recent major atlas of China note: 'China is one of the

[30] As when gold, for instance, developed from the teeth or excrement of reptiles; Vol. 5, pt. 2, p. 62.

[31] Su Ju-chiang (*1942*), p. 14. See also below, (*k*)(4). [32] Tegengren (1924), p. 163. [33] Rastall (1923), p. 70.

[34] Though this is evidence from the 19th century, it would be surprising if Chinese miners had not been able to make similar classifications of ore deposits long before then. For those who wrote about minerals, however, such precision was seldom of interest (and indeed might not even have been understood by them without familiarity with actual mines and deposits, or access to an informant who possessed that familiarity and a knack for explanations that could be understood by the neophyte).

Table 5. *19th century Chinese classifications of Yunnan copper deposits*

Vein designation	Appearance	Character of the ore
Dull vein (*kan-huan* 憨橏)	Dry colouring, thin ore content	No workable deposit
Mountain-covering vein (*phu shan huan* 鋪山橏)	Scattered and 'unrooted' (*wu ken* 無根)	Surface deposit with small output; float
Grass cover deposit (*tshao phi khuang* 草皮礦) OR bird's claw deposit (*chi kua khuang* 雞瓜礦)[a]	Gravel layer a few feet below the surface	Same as 'mountain-covering vein'; deposit will have a short life
Vertical vein (*shu sheng huan* 豎生橏)	Suspended straight down, without shoots	Too solitary; no large deposit
Grindstone vein (*mo phan huan* 磨盤橏)	Twisting and coiling downwards	Water problems after several years of mining
Suspended sword vein (*khua tao huan* 跨刀橏)	Enters the mountainside at an angle; sudden pinchings-out, followed by re-appearance; clearly demarcated from roof and floor [country rock]	Small veins brush-shaped;[b] if large, can be expected to be a massive deposit (*thang* 堂)
Bird's nest deposit (*chi wo khuang* 雞窩礦)	Easy to excavate, like grass cover deposit; gravel forms pockets like a bird's nest	Float in pockets; not more than a few litres in each pocket
River approaching deposit (*pen chiang khuang* 迸江礦)	(Possibly the tracing of derivative placer deposits back to their outcrop and vein)	Unlikely to be a rich deposit
Enter mountain deposit (*chin shan khuang* 進山礦)	(Possibly tracing of eluvial float to an outcrop and vein)	Could be a rich deposit
Divided massive deposit (*pai thang khuang* 擺堂礦)	Several unbroken veins like a bird claw	Possibility of a big deposit
Grand vein (*ta huan* 大橏)	More than one foot thick; many tens of feet in length. Hard, jagged rock. Difficult to find (reach? (*i shih pu neng ti khuang* 一時不能的礦))	Once found, there surely will be a series of massive deposits that can be worked for a long period

[a] *Huan* and *khuang* overlap considerably in their meanings. I have followed Sun in translating *huan* as 'vein' and ordinary usage in translating '*khuang*' as deposit.
[b] Possibly referring to numerous closely spaced small veins in a shear zone? Cf. Pearl (1973), p. 270.
Wu Chhi-chün (*1845*) ch. 1, pp. 2a–b; Sun (1964:1981), pp. 62–3; Yen Chung-phing (*1957*), p. 52. I am very indebted to Lung Tshun-ni for help in interpreting what Wu and Ni were saying.

few countries in the world which have relatively abundant mineral resources of all types. . . .'[35] At present, China has some 5,300 coal mines, 1,971 iron producing areas, 900+ copper producing areas and 1,000 gold mines. These are very widely distributed throughout the country.[36]

[35] Gan (1994), book I, p. 12.
[36] *Ibid.* The total of mineral deposits and occurrences in China is more than 200,000; Li Yü-wei *et al.* (*1993*), p. 27.

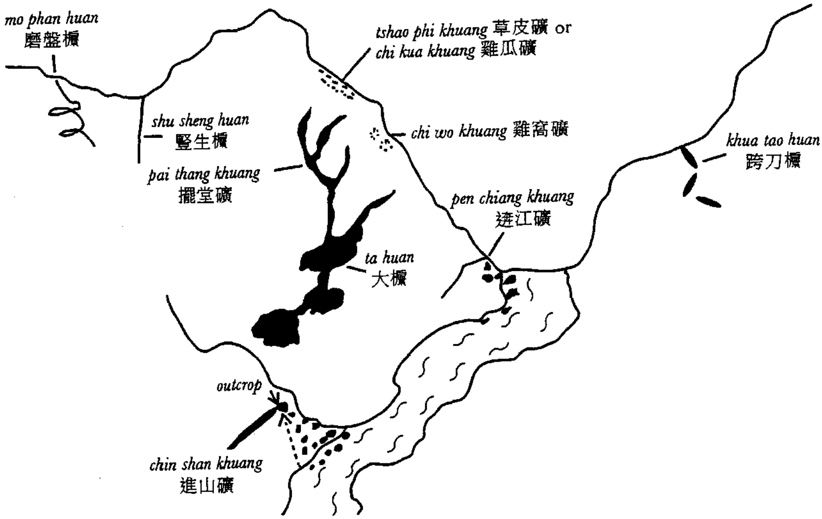


Fig. 9. Copper ore deposits of Yunnan as classified by the Chinese miners; for references, see Table 5.

On the other hand, Chinese deposits were typically small and irregular.[37] Part of the reason for the patchy quality of many deposits in China is that erosion has not proceeded sufficiently to form broad zones of secondary enrichment with rich and continuous deposits.[38] In addition, many of the deposits occur in limestone whose ready solubility is especially conducive to highly irregular deposits (Fig. 6).

The result is that China, despite its enormous size, did not have many regions noted for considerable deposits of particular minerals, though the small and irregular orebodies could be relatively rich in mineral content.[39] The major exceptions were the vast iron, limestone and coal deposits of the central Yangtze (Ta-yeh 大冶) area, the tin and copper of the southwest, the coal and iron of Shensi, Shansi and Inner Mongolia, and the gold of the northeast. Even in these cases, however, deposits that in their total represented considerable amounts were often irregular or scattered over wide areas.[40]

[37] In this, they tend to resemble the deposits of the United States east of Chicago, as in the Appalachian Mountains, rather than the much larger deposits west of Denver; Bain (1933), pp. 32–3. In China's west, too, mineral deposits may prove markedly superior overall to those in the east. However, with a few minor exceptions such as jade, these were not exploited in traditional times. Even in the early 1990s, 80% of China's so-far discovered mineral producing sites lay in areas to the east of 105° E longitude, i.e., the eastern one-half of the country; Gan (1994), book I, p. 13.

[38] Wong Wen-hao (1920), p. 54.

[39] A good example is the silver–iron–lead deposits of southern Chekiang and northern Fukien; Hsia Hsiang-jung *et al.* (*1980*), p. 293.

[40] This was true, for example, of the great copper ore deposits of Tung-chhuan 東川 in Yunnan; Ting (1915), p. 211.

On the other hand, geological forces have been kind to China in at least one very important way: in Shansi, seams of coal suitable for coking and deposits of iron ore frequently occur close to one another, together with fireclay for making crucibles or furnaces for smelting.[41] Hartwell has suggested that this explains why the Chinese apparently used coal 'extensively' in ferrous metallurgy long before it became important for heating and cooking in Chinese homes, a reversal of what occurred in Europe.[42]

(ii) *A regional breakdown of China's ore deposits*

One of the most influential perspectives to emerge at the time when modern geology was being established in China was Wong Wen-hao's identification of three distinct metallogenetic zones:[43]

(1) In the north, especially in Hopeh and the northeast, older pre-Cambrian (570+ million years ago) rocks; typically quartz veins in schists and gneisses. Veins generally small and rarely extend for any distance in strike or depth. Main metallic deposits are gold, silver, copper, lead and zinc.

(2) Central China, extending up into Shantung. Much intrusion of dioritic rocks. Around the edges of the intrusions, contact metamorphic deposits of iron, with lesser amounts of copper, lead, zinc.

(3) In the south, typically intrusion of granitic rocks. Vein deposits of all the nonferrous minerals. The central south China metallic belt serves as a good general example of the phenomenon of regional banding or zoning, where ores formed at high temperatures tend to occur closer to centres of igneous activity (e.g. granitic intrusions) while those formed at lower temperatures appear farther away.[44] Thus, in the Nan-ling 南嶺 area (including southern Kiangsi, southern Hunan and northern Kwangtung), high temperature ores of tin and tungsten predominate; in central Hunan, medium temperature ores of lead and zinc predominate; in western Hunan, low temperature antimony deposits are found; and finally, along the border areas between Hunan and Kweichow, low temperature mercury deposits appear.[45]

To get a somewhat more detailed picture of mining activity in China before the introduction of modern mining techniques, we can more usefully divide China in 16 mineral regions, as shown in Map 2.[46]

[41] Wei Chou-yuan (1946), p. 400; Nyström (1912), pp. 52 and 81; von Richthofen (1875), pp. 14ff, esp. pp. 15–16 and 19.

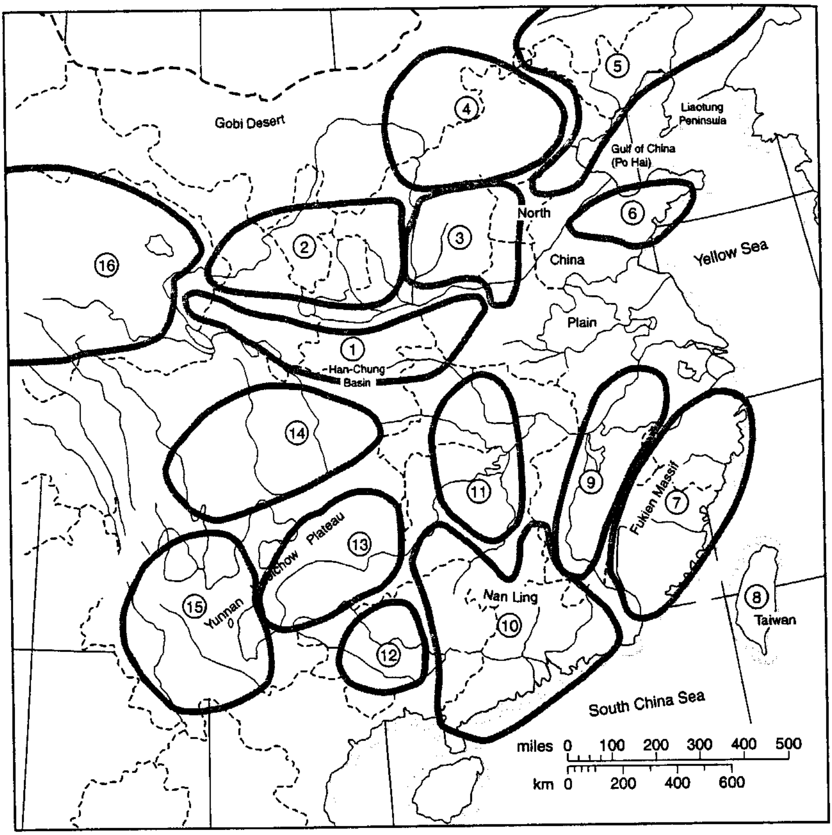
[42] Hartwell (1967), pp. 135–6. On the other hand, it could be that early texts do not mention domestic use of coal precisely because, where it occurred, there was nothing extraordinary about that use.

[43] Wong Wen-hao (1925).

[44] Bateman (1950), pp. 314–15, which notes some of the complexities of the theory that preclude exclusive focus on temperatures.

[45] Phan Chung-hsiang (*1951*), p. 140.

[46] This breakdown consolidates information from a number of sources, most importantly Weng Wen-hao (*1919*), pp. 25–46; Torgasheff (1930), chap. 2; Tegengren (1924); di Villa (1919); Wei Chou-yuan (1946); Hsieh Chiao-min (1973); Bain (1933); Gan (1994); Li Yü-wei *et al.* (*1993*). Minerals such as platinum, molybdenum, uranium, etc. that played no rôle in traditional mining are not included.



Map 2. Major mineral regions of China. Base map from Hsieh Chiao-min (1973), Map 1–2. For key to areas, see text.

(1) The Tsinling (Chhin-ling 秦嶺) metamorphic range: including (a) the mountainous region of southern Shensi south of the Wei 渭 River and extending to the northern parts of Szechwan; (b) the western extension of the Tsinling range into Tsinghai; and (c) the mountainous southwestern portion of Honan. Intensely folded sedimentary beds greatly metamorphosed by numerous igneous intrusions. In the central area, small coal deposits; some gold and iron (e.g. upper reaches of the Han 韓 River); copper. Mountainous southern Honan (and extending into northernmost Hupeh and even into Anhwei, lead and silver in metamophic rock; placer gold and iron; coal and graphite. Except for some iron sands, mineral deposits poor in the eastern section.

(2) The Northern Shensi/Eastern Kansu Mesozoic (225–56 million years ago) plateau. Sedimentary rocks with immense reserves of coal. Covered with thick layer of loess. Oil, iron, sulphur, arsenic, salt. Some silver, gold. Considerable copper along Yellow River in eastern Kansu.[47]

(3) The Shansi coal basin, consisting mainly of late Paleozoic and early Mesozoic (about 200+ million years ago) sediments; includes northern Honan but excludes northern Shansi. Coal, iron, sulphur, alum, copper, silver, zinc and salt. Small amounts of lead, mercury, gold (in early times).

(4) The Mongolian plateau, including northern Shansi. Mainly metamorphic and gneissic rocks, with occasional patches of Paleozoic (225+ million years ago) formations and Jurassic (135–180 million years ago) coal basins.[48] Coal, iron, gold, lead, silver, salt, mica, asbestos.

(5) The Northeast plain, including Heilungkiang, Kirin, Liaoning and northern Hopeh. Mainly gneiss, granite and schist, sometimes covered by sandstone, conglomerate and limestone. Many igneous intrusions. Eastern and northern regions expecially marked by extinct volcanoes and great sheets of lava.[49] Coal, iron, oil, gold (mainly in alluvial deposits in northern Manchuria along the Russian frontier), silver, copper, lead, zinc, asbestos, talc, magnesium, fluorite, sulphur, kaolin.

(6) Shantung peninsula and western Shantung. The peninsula itself is almost entirely composed of metamorphosed pre-Cambrian rock; part of a mountain range that continues into the Liao-tung 遼東 peninsula. Central Shantung massif rich in coal and copper. Gold (abundant in quartz fissure veins in pre-Cambrian gneiss), coal, iron, copper, lead/silver ore, copper/lead/zinc ores,[50] tin, diamonds, gypsum, clay and sandstone. Natural sulphur.

(7) Chekiang and Fukien porphyry region. Granite and quartz porphyry predominate. Chekiang: coal, magnetite, ironsand, copper, zinc, lead, silver, tin, alum (alunite), lime, gypsum. Fukien: coal, iron, ironsand, vein gold, silver, lead, tin, copper, zinc, alunite, kaolin.

(8) Taiwan. Rather low mineralisation because of absence of igneous intrusions. Northern Taiwan: coal, gold, copper, sulphur. Central mountain range and eastern coast: gold, copper, mercury, iron. Western Taiwan: coal, oil.

(9) Southern Anhwei and eastern Kiangsi (extending into southeastern Hupeh and northeastern Hunan) metamorphic region. Southern Anhwei: mountains mainly of granite, limestone and schist. Anhwei: (bituminous) coal, iron, copper, gold, silver, lead, alunite. Kiangsi: coal, iron, copper, silver, lead, gold, ceramic clay (including kaolinite).

(10) The Ling-nan 嶺南 mountain area (including the Wu-ling 五嶺 chain of Hunan, Kwangsi and Kwangtung and the Chiu-lien chain of Kiangsi and Kwangtung and the areas south of the mountains in Kwangtung). Much metamorphosed Paleozoic strata. West and northwest of Kwangtung: sandstone and limestone interspersed

[47] Kho Chün (1987), p. 226. [48] Couling (1917), p. 203.
[49] Richard (1908), p. 488. [50] Li Ching-hua (*1985*), p. 77.

with porphyry and granite.[51] Rich metallic deposits: tin, lead, zinc. Southern Kiangsi: coal, iron, copper, vein gold. Southern Hunan: anthracite and bituminous coal (very rich deposits in the southeastern part of the province). Many contact deposits: zinc/lead, copper, sulphur, tin, arsenic. Kwangtung: coal, iron, magnesium, gold, silver, copper, lead, tin, tungsten, stibnite, pyrite (sulphur).

(11) Western Hupeh and Hunan. Western Hupei: copper, lead, zinc, coal. Western Hunan: coal and iron; vein gold, pyrite (sulphur), copper, tin, zinc; mercury (in Wu-ling shan 五嶺山 area), realgar/orpiment.

(12) Paleozoic Kwangsi plateau. Composed mainly of limestone and sandstone, but also slate veined with porphyry and granulite. Sizeable granitic mass in centre, north of Nan-ning 南寧. Considerable clay-stone in the west.[52] Tin and bismuth (in the western areas); coal and iron (extensively); some argentiferous lead deposits in metamorphic rock; antimony, gold, mercury. Arsenic (arsenopyrite).

(13) The Kweichow Plateau. Limestone predominates, with much schist and red sandstone. Seams of porphyry and granite. Extensive iron and coal mining; mercury, antimony, copper, gold, zinc, argentiferous lead, sulphur, realgar/orpiment, nitre, marble.

(14) Mesozoic basin of Szechwan. Metallic minerals occur in the mountains (mainly of gneiss, granite and schist) surrounding a basin of red and green sandstone of the Triassic period; coal, iron, salt, etc. occur in the carboniferous rock underlying the sandstone. Northern mountains: copper, argentiferous lead, placer gold, tin. Western mountains: gold (in ancient alluvials as well as vein deposits), copper, argentiferous lead. Western basin: salt (rock and brine), oil, sylvite (potassium chloride), natural gas. Eastern basin: coal and iron (much of it low grade siderite).

(15) Yunnan. Because of its geology, the metallic ore deposits of Yunnan are extremely rich. Apart from Hunan, there is no other area of China that can compare with it. Much of the province is covered with Paleozoic limestone which forms the country rock of the major tin deposits at Ko-chiu 箇舊 as well as serving as the source of a great deal of fine marble.[53] Well over half of all the streams in Yunnan are auriferous.[54] Southeastern Yunnan: tin, coal, antimony, lead, bismuth, copper, mercury, gypsum. Eastern Yunnan: coal; lead, zinc and copper (in contact or replacement deposits), mercury. Central Yunnan: This is the area of very extensive (but, except for Tung-chhuan 東川, not very rich) copper deposits.[55] The deposits are mainly of two kinds: replacement or fissure vein deposits in limestone and shale and secondary enrichment deposits in lava. Also, asbestos, gold, silver. Western Yunnan: lead, zinc, iron, mica, sulphur, mercury, arsenic, gold.

(16) Sinkiang. Despite deposits of copper, zinc, lead, silver and gold, virtually no mining in traditional times.

[51] Richard (1908), p. 203. [52] Richard (1908), p. 196. [53] Moore-Bennet (1915), p. 226.

[54] Torgasheff (1930), p. 125. A sampling between 1911 and 1913 of 700+ streams in southwest China found more than 430 of them to contain gold; Moore-Bennet (1915), p. 224.

[55] Weng Wen-hao (*1919*), p. 49.

(5) THE EFFECTS OF CHINESE ORE DEPOSITS ON MINING

Assessments by Westerners who arrived in China in the 19th century tended to overstate her mineral riches.[56] In the case of gold, the roots of this 'incurable habit' go back to the early European explorers whose hopes for riches often coloured their assessments of the unknown lands they visited.[57] In the case of both gold and other minerals, early Western visitors to China were prone simply to misread the evidence they saw, confusing widespread distribution with abundant deposits. Among 19th century observers of Chinese mining guilty of this error was Ferdinand von Richthofen who, in spite of his generally accurate and incisive comments on much of Chinese mining at that time, overestimated Chinese iron and coal resources because of the many but small coal mines and iron smelters he saw.[58] Of course, some of the early Western observers may simply have been carried away by the kind of persistent optimism that is so much a characteristic of miners and mining communities.[59]

The reality of Chinese ore deposits, that they were for the most part small and irregular, influenced Chinese mining to a degree that is hard to overstate.[60] Together with the vast pool of cheap labour, these limited and unpredictable deposits assured that most of Chinese mining would be of a type sometimes referred to as artisanal mining. This mining tradition was marked by small-scale, relatively crude methods that were nonetheless the most economical or even the only economical methods available to Chinese miners. When foreign mining engineers first attempted to introduce modern mining methods, they all too often found that 'working costs could not be lowered sufficiently to provide interest and amortisation on the equipment investment.'[61] There is no reason to be surprised then that Chinese mining techniques, despite impressive beginnings, generally failed to display comparable advances during the following two millennia.

[56] For a discussion of such overstatements in the late 19th and early 20th centuries in regard to the province of Yunnan, and the motivations behind the exaggerations, see Walsh (1943).

[57] Davidson (1903), p. 462.

[58] Cressey (1955), p. 131; Read (1920), p. 301. Cressey legitimately criticises von Richthofen for having jumped to conclusions on the basis of too hasty travels, but he himself on the preceding page gives a summary of Chinese exploitation of minerals that is very mistaken: 'China has developed one of the world's distinctive cultures, but it has done so *largely without the use of minerals*. The Chinese live so close to the products of the soil that theirs has been described as a vegetable civilisation. This may have sufficed for the past, but it will not meet the needs of the future.' (p. 130; my italics)

[59] Becher (1887), pp. 28–9.

[60] The well-known and extensive Shansi iron deposits are a particularly good example: because they occurred in thin beds, they were not suitable for working by the modern mining methods available early in this century. Moreover, the ore was distributed in small masses which, because of the varying chemical composition, limited their value for large-scale industrial use. Read (1910a), pp. 199–200; Smith (1926), p. 67.

[61] Read (1920), p. 298; Read (1910a), p. 122; Matthieu (1924), p. 450.

(e) THE PRODUCTS OF CHINESE MINING

(1) Major Non-ferrous Metals

(i) *Copper*

(α) *The discovery and earliest use of copper in China*[1]

Like other early experimenters with metal, the Chinese probably came to know copper by finding bits or pieces of very pure uncombined or 'native' copper.[2] Although copper nodules, with their corroded, purplish-green, greenish-black or brownish colour, were less immediately recognisable than gold nuggets, a certain amount of experience made their detection relatively easy. Moreover, when scratching or abrading by harder stones revealed their metallic yellowish-red colour, they would have been unmistakable as some special kind of stone.[3] When worked with a hammer, these lumps could even take on an appearance not unlike gold.[4]

The amount of usable native copper available in early China and elsewhere has been a matter of some debate.[5] Although native metals typically occur only as minute particles, this is far more true for gold than for copper.[6] Especially when metals first began to be used, copper must have been found fairly often in pieces large enough

[1] The opening remarks of this section have as their unspoken assumption that the possibilities of copper were discovered by the Chinese independent of influences from copper-using peoples beyond the Chinese cultural area. I still consider this to be very possibly the way things happened. Nevertheless, after this section had been essentially completed, my attention was drawn by Victor Mair to an important article by An Chih-min (*1993*) that stresses the possibility that it was in the northwestern Chhi-chia culture (c. –2000 to c. –1600) that we see the first extensive production and use of copper/bronze implements in China. This would strongly imply a knowledge of copper coming into China through contacts with people to the north and west. Even should this prove to be the case, however, most of what is said here about finding *deposits* of copper will still hold true.

[2] The modern Chinese term for native copper is *tzu jan thung* 自然銅. When traditional texts use this term, however, they are normally referring to pyrites and *not* to native copper. Hsia Hsiang-jung *et al.* (*1980*), p. 243; Chang Hung-chao (*1927*), pp. 367ff.; Wang Chia-yin (*1957*), p. 59; Vol. 5, pt. 2, p. 200; fn. g. For pure or native copper, the term *tzu lai thung* 自來銅 was sometimes used, as in Yunnan during the Chhing; Yen Chung-phing (*1957*), p. 53.

[3] Coghlan (1951), p. 19.

[4] Rickard (1932), pp. 95–6; Aitchison (1960), p. 11. Native copper tends to be extremely pure (in the 99.9% range) even by comparison with native silver (99%) and native gold (which can easily contain more than 10% impurities such as silver, copper and mercury); cf. Patterson (1971), pp. 301–2; Aitchison (1960), p. 174. It should be noted that the early Chinese do not seem to have worked copper very extensively by hammering; cf. below, fn. 9.

[5] Contrast, for example, Hodges (1964), p. 65 with Rickard (1932), p. 106 and Tylecote (1992), p. 1. For the general question of copper's rôle in the emergence of true metallurgy, Noel Barnard's recent comments, including his hypothesis that one finds 'no significant transitional period of experiment involving lithic applications and the use of native copper' because 'the forerunner of metallurgy in China was the potter', are indispensable; cf. Barnard (1989), pp. 186–92 (the citations come from p. 186).

[6] It is not uncommon for a million gold particles to weigh less than an ounce; Read (1934), pp. 382–3. By contrast, as late as the end of the last century, native copper 'in lumps as big as a man's fist' were still to be found in Shantung (Anon. (1898–1899), p. 642). At the other end of China, miners in Yunnan frequently met with nuggets too large for them to use and which had to be left in the ground because the miners had no way of breaking them up into smaller pieces (von Richthofen (1872b), p. 74). In this century, pieces of native copper measuring 30 × 40 cm or more could still be found in that area of eastern Kansu in which some of China's earliest copper artefacts have been discovered (Hsia Hsiang-jung *et al.* (*1980*), p. 244); cf. below.

to be transformed into a small blade, an ornament or something similar.[7] How often this occurred, however, is difficult to estimate because many deposits available in early times were eventually worked out, leaving behind no traces, or were abandoned for other reasons and forgotten. About all one can say for certain is that the process of ore formation in oxidised zones of deposits assures that *some* native copper will always be produced, though it may be a very small percentage compared with the total amount of oxidised ores.[8]

The form in which native copper appeared also influenced its 'usability' in early times. Before the discovery of melting and casting, making use of copper had to be a lithic craft, involving mainly the shaping of pieces of native copper by means of hammering or grinding.[9] However, the considerable hammering often required to transform pieces of copper into desired shapes (when, indeed, this was possible[10]) tended to harden the copper and cause it to crack. This problem could be solved by the process of annealing (heating the metal so as to relieve the stress induced by hammering).[11] However, the Chinese do not seem to have discovered annealing until quite late, perhaps not until about the middle of the –1st millennium.[12] Fortunately for the early miners, native copper could also appear in thin plates or dendritic forms. These forms not only were especially easy to recognise but also lent themselves far more easily to shaping, at least into small objects like awls or pins but sometimes also into flat forms such as blades.[13] It therefore seems quite possible, if unprovable, that a far greater abundance of *usable* native copper compared to gold led to the working of copper before gold not only in western Asia and North America but also in China.[14] The early cold working of copper was then followed by

[7] Patterson (1971), pp. 296–7; Forbes (1954), p. 85; Hsia Hsiang-jung *et al.* (*1980*), p. 15.

[8] Patterson (1971), pp. 294–5; Aitchison (1960), p. 20. Patterson, who provides the most sophisticated analysis of this question to date, guesses that 'the fraction of native copper in the oxidised zones of all the world's ores (outside of Lake Superior) was about 0.002.' Even if true, however, this does not help us much in considering the deposits of any given area such as north China since the amount of native copper present could vary considerably from deposit to deposit.

[9] How extensively and for how long this working of copper prevailed varied widely from area to area. In China, its importance was far less than in other civilisations: '. . . in China, the general lack of a true Chalcolithic Age (i.e., one featuring the working of native copper by artisans familiar with the principles of annealing and cold hammering) . . . was simply due to the fact that the forerunner of metallurgy in China was the potter – there was no significant transitional period of experiment involving lithic applications and the use of native copper.' Barnard (1989), p. 186; Barnard (1983), p. 251. (See also Watson (1984), p. 329.) Nevertheless, Barnard *does* allow for some working to finish objects previously formed by casting, as when a blade is hammered to increase its sharpness. But this he insists on considering 'finishing' rather than 'working' since it has 'little, if anything, to do with the ultimate design and manufacture' of the items. [Private communication]

[10] Coghlan (1951), pp. 19–20.

[11] Shepherd (1980, p. 162) has suggested that the idea of annealing may have come from the practice of hardening wooden tools or weapons in a fire.

[12] Barnard & Satō contend that annealing 'became known (possibly introduced [from beyond China's borders]) some time after the Chinese founders had discovered iron as a metal capable of being cast.' Barnard & Satō (1975), p. 71. Hua Chueh-ming, on the other hand, holds that annealing in China dates from the late Neolithic period; Hua Chueh-ming (*1987*), p. 68. The earliest annealing in western Asia (in what is now south-eastern Turkey) occurred as early as the –8th millennium; Muhly (1988), p. 5.

[13] Coghlan (1951), p. 19; Forbes (1954), p. 585; Aitchison (1960), pp. 20–1.

[14] Patterson (1971), p. 299; Barnard (1989), p. 188. Barnard also suggests that the easy availability of usable native copper could actually have encouraged continued use of worked copper and delayed the emergence of true metallurgy, as happened with the Lake Superior (North America) hunting cultures. This would have been

the discovery of heat-softening to assist in shaping the metal and, finally, by melting and the shaping of the melted metal by casting.[15] This far easier and therefore less expensive process inevitably encouraged increased demand for a wide variety of copper implements and ornaments.[16]

On the basis of archaeological remains so far discovered, two areas have emerged as possible locations for the first use of copper in China: the Central Plain area of north China and eastern Kansu to the northwest. In both areas, a number of copper specimens dating from approximately −2,000 have been excavated and there is no consensus on which area witnessed the earlier use of copper.[17] The debate is complex in the extreme, involving as it does not only limited archaeological evidence but also questions of the quality of excavation techniques and reports, references to evidence that has never been properly published and widely varying levels of metallurgical expertise. It is likely to be a long time before these issues have been sorted out, perhaps on the basis of significantly more evidence than is currently available. What we can now say with fair certainty, however, is that Chinese experiments with making artefacts of copper and, especially in Kansu, bronze were well underway by the end of the −3rd and the beginning of the −2nd millennia.[18]

Attempts to push that dating back much further have relied heavily on a single artefact discovered in 1975 in the Ma-chia-yao 馬家窯 remains at Lin-chia 林家 in Tung-hsiang 東鄉, just southwest of Lan-chou 蘭州 in Kansu: a 12.6 cm bronze blade, cast in an open mould, that some scholars have taken to date from perhaps −2800 to −3000.[19] In the original excitement surrounding this discovery, probably not enough attention was given to the danger of attaching too great a significance

all the more likely after the discovery of heat-softening greatly increased the supply of usable native copper; cf. Coghlan's contention (1951, p. 20) that 'native copper in the massive form could have been useful only to a people who were in the possession of the knowledge of how to soften copper through the agency of heat.' The very rapid movement of the Chinese from working to casting copper was undoubtedly made possible, as Barnard has frequently stressed, by the experience of Chinese potters in working with the very high temperatures necessary for melting, as opposed to softening, metals.

[15] Unfortunately, we cannot determine just when this happened, even assuming we had the relevant artefacts, since it is virtually impossible to distinguish native copper that has been melted from copper smelted from pure ores; Thompson (1958), p. 1; Tylecote (1992), p. 1 and Barnard (1989), p. 188, fn. 29 (which includes a useful bibliography on this subject). About all we can say for certain is that once pottery kilns had been developed to achieve temperatures in the 1050–1100 °C range, the potential for melting copper fully, which requires a temperature of 1083 °C, was present; Shepherd (1980), p. 162.

[16] For the earliest evidence so far studied on the beginnings of melting and casting in the area of the north China plain, see Li Ching-hua (*1985*) which suggests that, by −2000, Chinese metalworkers were already using different kinds of furnaces for melting and for smelting. On the need for different kinds of furnaces for these two purposes, cf. Barnard (1989), pp. 192–5.

[17] Hsia Hsiang-jung *et al.* (*1980*), pp. 198, 242; Anon. (*1983a*); Murray (1985), p. 264; Kho Chün (1987), pp. 225–8; Chang Kwang-chih (1977), p. 196, Barnard (1991), pp. 25, 58–9 and *passim*. The earliest of these specimens may be a bronze blade excavated at Yung-teng 永登 in Kansu that may date from as early as −2300 (Murray (1985), p. 262) but Barnard raises many questions about this find (Barnard (1991), p. 7) that incline him to believe that it is a 'cultural intrusion'. For all of these remains, the place now to start is with the recent critical review of the evidence by An Chih-min (*1993*) and, in English, Barnard (1991) which focuses on the problems of interpreting the evidence.

[18] Watson (1984), pp. 332–3.

[19] Ma Cheng-yuan (1980), p. 1; Murray (1985), p. 262; Mei Jianjun & Ko Tsun (1995), p. 233.

to any isolated, unique artefact.[20] Moreover, while the 5–10 per cent tin content of this blade is high enough to suggest conscious addition of the tin (either in the form of the metal itself or, more likely, as a tin ore), this suggestion is difficult to accept. Tinstone is much less easy to identify than other metallic ores (cf. below, Section (*e*)(1)(ii)(α)) and was therefore presumably discovered considerably later than either native copper or the colourful copper carbonate ores. For the time being, then, the most likely explanation is that this artefact, if indeed it does date from the period proposed, was produced from a copper deposit that happened to be particularly rich in tin.[21] Such deposits are far more likely to be found in south China[22] but they have occurred also in north China as, for instance, at Lai-wu 萊蕪 in Shantung, where copper and tin were produced from the same deposit at least as early as the Thang (Map 3).[23] Lin-ju 臨汝 in Honan, long known as a tin producing site, has been revealed by recent discoveries to have been an early copper mining site.[24] The Ta-chhing 大井 mines in Inner Mongolia, which were worked at least from the beginning of the –1st millennium, and probably earlier, also made use of a large deposit of a copper–tin ore.[25]

As skilful as the early Chinese might have become at finding and using native copper, the overall supply would never have permitted objects made from it to constitute more than a tiny fraction of the total production of even small tools, ornaments, etc.[26] Only with the discovery of ores from which copper could be smelted was the way opened to production on a significant scale of not only copper but also bronze objects.

Just how this discovery was made must remain a matter of speculation. The bright colours of the carbonate ores, malachite and azurite, undoubtedly helped, together with the fact that these ores were commonly present with deposits of native copper and were also relatively easy to smelt. Once the possibility of consolidating or shaping native copper by melting had been discovered, there was high likelihood that oxide or carbonate ores would come to be smelted by accident.[27] On the other

[20] For a discussion of this point, see Patterson (1971), p. 306; for an example of how it has led one scholar into egregious error in dating the beginnings of bronze in China, see fn. 42 below. (Equally uncritical reliance has also been placed more than once on shaky radiocarbon dates.) Barnard discusses in detail the questions surrounding this artefact, and suggests that, in the absence of further evidence, we view it as a 'cultural intrusion' rather than a locally manufactured product; Barnard (1991), pp. 2–7. On the other hand, scholars such as Muhly (1988, p. 14) are prepared to accept that this blade was locally manufactured, contending that it fits in well with other evidence of the use of metal in the chalcolithic Chhi-chia culture.

[21] This could well have been the case even with a deposit of native copper since such deposits are frequently extremely heterogeneous, with small angular crystals embedded in gangue that can consist of other minerals; cf. Tylecote (1992), p. 1. It could be that efforts to combine these crystals into a larger piece of copper by melting inadvertently introduced tin ore from the gangue.

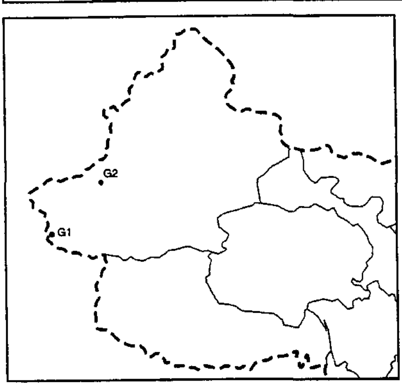
[22] Hsia Hsiang-jung *et al.* (*1980*), p. 199; Barnard (1989), p. 191. [23] Amano (*1953*), p. 234.

[24] Cf. Map 4 (H) (Ju-chou 汝州 is present-day Lin-ju) and Li Ching-hua (*1985*), p. 75.

[25] Zhu Shoukang (1986), p. 9.

[26] All the more so because, as we have noted, copper sometimes appears in so hardened a form that it cannot be mined with traditional tools; besides the reference to von Richthofen in fn. 6, see also Brown (1923), pp. 100, 101 and 105.

[27] Rostoker & Dvorak (1991), p. 5.



Map 3. Pre-20th century copper mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A	Liaoning	H	Kiangsu	P	Hunan
B	Hopeh	J	Anhwei	Q	Szechwan
C	Shantung	K	Honan	R	Kweichow
D	Shansi	L	Chekiang	S	Kwangtung
E	Shensi	M	Fukien	T	Kwangsi
F	Kansu	N	Kiangsi	U	Yunnan
G	Sinkiang	O	Hupeh	V	Kirin

Caption to Map 3. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 3

	Site		Further Identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
A1	Chin-chou	錦州							X	
A2	Jui-chou chi-shan	瑞州雞山	Hsing-chheng	興城					X	
B1	Fei-hu	飛狐	Lai-yuan	淶源			X			
B2	Thang-hsien	唐縣					X			
B3	Po-hai shou yü chhien hu so	勃海守御千戶所	Chhang-phing	昌平					X	
B4	Phing-chhüan	平泉								X
C1	Lai-wu	萊蕪					X		X	
C2	I-shui	沂水					X			
C3	Chhi pao shan	七寶山	I-tu lin chhü hsien	益都臨朐縣					X	
C4	Lin-chhü	臨朐								X
C5	Chü-chou	莒州								X
D1	Shao-shan	少山	Hsi-yang	昔陽	X					
D2	Pai-ma shan	白馬山	Yang-chhüan	陽泉	X					
D3	Ku-teng shan	鼓鐙山	Yuan-chhu	垣曲	X					
D4	Hsuan-yung shan	縣雍山	Thai-yuan	太原	X		X			
D5	Wo-shan	淒山	Lü-liang	呂梁	X					
D6	Yun-chheng tung kou	運城洞溝				X				
D7	Chhü-wo	曲沃					X		X	
D8	I-chheng	翼城					X		X	
D9	Phing-lu	平陸					X			X
D10	Chieh-hsien	解縣					X			
D11	Wen-hsi	聞喜					X		X	
D12	Meng-hsien	盂縣					X			
D13	Wu-thai	五台					X		X	
D14	Li-chheng	黎城					X			
D15	Yang-chheng	陽城					X			
D16	Chiang-chou	絳州					X		X	X
D12	Yü-chou	盂州							X	
D17	Yuan-chhü	垣曲							X	X
D18	Pao-te chou	保德州							X	
E1	Fu-yü shan	符禺山	Wei-nan	渭南	X					
E2	Shih-tshui shan	石脆山	Hua-hsien	華縣	X					
E3	Sung-kuo shan	松果山	Hua-yin	華陰	X					
E3	Yang-hua shan	陽華山	Hua-yin	華陰	X					
E4	Yü-shan	禺山	Ching-pien	靖邊	X					
E5	Yü-tzhu shan	羭次山	Chhang-an	長安	X					
E6	Chung-wei shan	蟲尾山	Lo-nan	洛南	X		X			

Key to Map 3 (*cont.*).

	Site		Further Identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
E7	Shang-lo	上洛					X			
E8	Shang-chou	商州					X			
E9	Lung-chou	隴州						X		
E10	Hsing-chou	興州						X		
E11	Ning-chhiang	寧羌	Ning-chhiang	寧強					X	
E12	Lueh-yang	略陽							X	X
E13	Lan-thien	藍田							X	
E14	Hsien-ning	咸寧							X	
E15	Chou-chih	周至							X	
E16	Chhang-an	長安							X	
F1	Phing-liang	平涼					X			
F2	Chheng-chi	成紀					X			
G1	Nan-erh	難兒				X				
G2	Ku-mo	姑墨				X				
H1	Chiang-tu	江都					X			
H2	Liu-ho	六合					X			
H3	Chü-jung	句容					X			
H4	Li-shui	溧水					X			
H5	Li-yang	溧陽					X			
H6	Wu-hsien	吳縣					X			
H7	Tan-thu	丹徒					X			
H8	Shang-yuan	上元					X			
H9	Yang-chou	揚州	Chiang-tu	江都					X	
H10	I-chen	儀真							X	
J1	Tan-yang	丹陽	Hsuan-chheng	宣城		X	X			
J2	Chhüan-chiao	全椒					X			
J3	Thien-chhang	天長					X			
J4	Chhu-chou	滁州					X			
J5	Lu-chiang	廬江					X			
J6	Tang-thu	當塗					X			
J7	Nan-ling	南陵					X		X	
J8	Chhiu-phu	秋浦	Kuei-chhih	貴池			X			
J9	Chhing-yang	青陽					X			
J10	Hung-hsien	虹縣	Ssu-hsien	泗縣			X			
J11	Chhing-liu	清流					X			
J12	Fan-chhang	繁昌							X	
J13	Thung-ling	銅陵							X	
K1	Thai-hang shan	太行山	Hui-hsien	輝縣	X					
K2	Phing-lu	平陸					X			
K3	I-yang	伊陽	Sung-hsien	嵩縣			X			
K4	Nan-yang	南陽					X			
K5	Kuo-chou	虢州						X		
K6	She-hsien	涉縣							X	
K7	Chen-phing	鎮平							X	
L1	Hai-yen chang shan	海鹽章山	An-chi	安吉		X				
L2	Wu-khang	武康					X		X	
L3	Chhang-chheng	長城	Chhang-hsing	長興			X			
L4	An-chi	安吉					X		X	
L5	Yü-hang	餘杭					X			
L6	Chien-te sui an	建德遂安					X			

Key to Map 3 (*cont.*).

	Site		Further Identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
L7	Feng-hua	奉化					X			X
L8	Li-shui	麗水					X			
L9	Chin-hua	金華					X		X	
L10	An-ku	安固	Jui-an	瑞安			X			
L11	Chhu-chou	處州	Li-shui	麗水				X		
L12	Chhang-hsing	長興							X	
L13	Lung-chhüan	隆泉							X	
L14	Phing-yang	平陽							X	
L15	Shao-hsing	紹興							X	
M1	Yu-hsi	尤溪					X			
M2	Chien-hui	建徽	Chien-ou	建甌			X			
M3	Chien-yang	建陽					X			
M4	Shao-wu	邵武					X		X	
M5	Chhang-thing	長汀					X		X	
M6	Sha-hsien	沙縣					X			
M7	Chien-an	建安					X			
M8	Chien-chou	建州						X		
M9	Thing-chou	汀州						X		
M10	Chang-chou	漳州	Lung-hsi	龍溪				X		
M11	Nan-chien chou	南劍州						X		
M12	Shao-wu chün	邵武軍						X		
M13	Chhüan-chou	泉州						X		
M14	Fu-chou	福州						X		
N1	Hung-chou	洪州	Nan-chhang	南昌			X			
N2	Hsun-yang	潯陽	Chiu-chiang	九江			X			
N3	Pheng-tse	彭澤					X			
N4	Jao-chou	饒州	Po-yang	波陽			X	X		
N5	Le-phing	樂平					X			
N6	Pho-yang	鄱陽					X			
N7	Yuan-chou	袁州	I-chhun	宜春			X			
N8	Hsin-chou	信州	Shang-jao	上饒			X	X		
N9	Nan-an chün	南安軍	Ta-yü	大庾				X		
N10	Chhien-chou	虔州	Kan-chou	贛州				X		
N11	Chhien shan chhang	鉛山場	Hsin-chou	信州				X		
N12	Te-hsing	德興							X	
N13	Chhien-shan	鉛山							X	
N14	Jui-chou	瑞州	Kao-an	高安					X	
O1	Thung-lü shan	銅綠山	Ta-yeh	大冶	X					X
O2	Yung-hsing	永興					X			
O3	Wu-chhang	武昌	O-chheng	鄂城			X		X	
O4	Yang-hsin	陽新								X
O5	An-lu	安陸								X
O6	Ching-shan	京山								X
O7	Nan-chang	南漳								X
O8	Fang-hsien	房縣								X
O9	Chu-shan	竹山								X
O10	Ho-feng	鶴峰								X
O11	Chhang-le	長樂								X
O12	En-shih	恩施								X
O13	Hsien-feng	咸豐								X
O14	Li-chhuan	利川								X
O15	Chien-shih	建始								X

Key to Map 3 (*cont.*).

Site			Further Identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
P1	Chhang-sha	長沙					X			
P2	Phing-yang	平陽	Kuei-yang	桂陽			X			
P3	Kao-thing	高亭	Yung-hsing	永興			X			
P4	I-chang	義章	I-chang	宜章			X		X	
P5	Than-chou	潭州						X		
P6	Chiao yuan hsien	茭源縣	Heng-chou	衡州				X		
P7	Chhen-chou	郴州					X	X	X	
P8	Heng-chou	衡州	Heng-yang	衡陽					X	
P9	Chhen-hsi	辰溪							X	
P10	Chhang-ning	常寧								X
P11	Sui-yang	綏陽								X
P2	Kuei-yang	桂陽								X
P12	Sui-ning	綏寧								X
P13	Sang-chih	桑植								X
Q1	Ling-kuan	靈關	Lu-shan	廬山		X				
Q2	Kuo-hsi	國徙	Thien-chhüan	天全		X				
Q3	Yen-tao	嚴道	Ying-ching	榮經		X	X			
Q4	Chhing-i	青衣	Ya-an	雅安		X				
Q5	Chin-chhüan	金泉	Chin-thang	金堂			X			
Q5	Chin-shui	金水	Chin-thang	金堂			X			
Q6	Lin-chhiung	臨邛	Chhiung-lai	邛徠			X			
Q7	Yang-an	陽安	Chien-yang	簡陽			X			
Q8	Lu-shan	廬山					X			
Q9	Thung-shan	銅山	Chung-chiang	中江			X			
Q10	Fei-niao	飛鳥					X			
Q11	Shih-ching	石鏡					X			
Q12	Tzu-chou	梓州	San-thai	三台				X		
Q13	Liang-shan	梁山	Liang-phing	梁平					X	
Q14	Hui-chhuan	會川	Hui-li	會理					X	X
Q15	Chhiung-chou	邛州								X
Q16	Li-han	黎漢								X
Q17	Le-shan	樂山								X
Q18	Chien-chhang	建昌	Hsi-chhang	西昌						X
Q19	Hung-ya	洪雅								X
Q20	Ma-pien	馬邊								X
Q21	Phing-shan	屏山								X
Q22	Yen-yuan	鹽源								X
Q23	Mien-ning	冕寧								X
Q24	Yun-yang	雲陽								X
Q25	Chieh-lien	界連	Feng chieh	奉節						X
R1	Wei-ning	威寧								X
R2	Ta-ting	大定								X
S1	Thung-ling	銅陵	Yang-chhung	陽春			X			
S2	Lien-shan	連山					X	X		
S3	Ying-chou	英州						X		
S4	Shao-chou	韶州						X		
S5	Kuang-chou	廣州						X		
S6	Lien-chou	連州						X		
S7	Kuei-yang	桂陽						X		
S8	Yang-shan	陽山							X	
S9	Chhü-chiang	曲江							X	
S10	Ying-te	英德							X	

Key to Map 3 (*cont.*).

	Site		Further Identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
S11	Hui-yang	惠陽								X
S12	Chhao-an	潮安								X
S13	Shao-kuan	韶關								X
S14	Kao-yao	高要								X
S1	Yang-chhun	陽春								X
T1	Lin-ho	臨賀	Ho-hsien	賀縣			X		X	
T2	Pin-chou	賓州	Pin-yang	賓陽						X
T3	Lin-kuei	臨桂					X			X
T4	Kung-chheng	恭城								X
T5	Nan-tan	南丹								X
T6	Tshang-wu	蒼梧								X
T7	Yung-chou	邕州								X
T8	Yu-chiang chou	右江州								X
U1	Yü-yuan	俞元	Chheng-chiang	澄江		X				
U2	Lai-wei	萊唯	Wen-shan	文山		X				
U3	Ai-lao	哀牢				X				
U4	Ta-li	大理							X	
U1	Sa-yi shan	薩矣山	Chheng-chiang	澄江					X	
U5	Tung-chhuan	東川							X	X
U6	Lu-nan	路南							X	X
U7	Lo-tzhu	羅次							X	X
U8	Wu-sa	烏撒	Chen-hsiung	鎮雄						X
U9	Chan-i hsien	霑益縣							X	
U10	Yung-ning	永寧							X	
U11	Pao-shan	保山							X	
U12	Hui-tse	會澤							X	X
U13	Hsun-tien	尋甸								X
U14	Yung-shan	永善								X
U15	Ta-kuan	大關								X
U16	Lu-tien	魯甸								X
U17	Ning-chou	寧州	Hua-ning	華寧						X
U18	Yuan-chiang	元江								X
U19	I-men	易門								X
U20	Shun-ning	順寧	Feng-chhing	風慶						X
U21	Yung-pei	永北	Yung-sheng	永勝						X
U22	Li-chiang	麗江								X
U23	Meng-tzu	蒙自								X
U24	Lu-chhüan	祿勸								X
U25	Wu-ting	武定								X
U26	Nan-an	南安								X
U27	Ting-yuan	定遠	Mou-ting	牟定						X
U28	Yun-lung	雲龍								X
U29	Theng-yueh	騰越								X
U30	Khun-yang	昆陽								X

hand, an entirely different kind of accident, perhaps a chance smelting in a pottery kiln, could also have been the key stimulus.[28]

Recently discovered crucibles in what is today Liaoning province suggest that experiments with the smelting of copper ores were occurring as early as the −4th millennium, at least in this area.[29] Smelting remains found in Honan and Shantung leave little doubt that smelting was carried on in many north Chinese localities during the second half of the −3rd millennium.[30] In the northwest, copper items (hatchet blades, knives, awls, ornaments, etc.) from the Chhi-chia culture, perhaps dating from around the beginning of the −2nd millennium, have been revealed by electron probe examinations to be made from a very pure copper.[31] This is usually an indicator of native copper, or just what we would expect. But the copper contains more iron and arsenic than is usually found in native copper, thus suggesting the possibility of smelting.[32] Although there is as yet little evidence to suggest copper smelting south of the Yangtze at an equally early period, recent discoveries are adding greatly to our previously poor understanding of the early bronze age in south China.[33] Given the existence of rich oxidised copper ore deposits that extended up to 100 m in depth,[34] it is not surprising to find that a bronze industry was thriving in certain localities at least by the middle of the −2nd millennium. Thus the beginnings of copper smelting in south China could well date from −2000 or even earlier.[35]

It was not until considerably later that the Chinese were able to make use of the copper sulphide ores which, though far more abundant than oxides, were considerably more difficult to smelt and could also be as costly as any traditional smelting techniques.[36] The first evidence for the use of a sulphide ore in China was discovered

[28] Or perhaps even a chance melting in a domestic fire; cf. Thompson (1958), p. 3. In the West, annealing may just possibly have provided an important clue, introducing metalworkers to the concept that metals can be altered by high heat; Hodges (1970), p. 48. That would still leave, however, an imaginative leap of no small proportions to arrive at the idea that metals could be extracted from rocks by the use of heat. In any case, if the hypothesis that annealing did not appear in China until the mid-Chou is correct, annealing obviously played no rôle there in the discovery of smelting.

[29] Mei Jianjun & Ko Tsun (1995), pp. 234–5.

[30] Li Ching-hua (*1985*), pp. 75–6; Barnard & Satō (1975), p. 11, n. 14. Evidence so far unearthed suggests – and it is a conclusion that fits well with geological and metallurgical realities – that early Chinese copper smelting relied overwhelmingly on the green carbonate ore malachite (*lü chhing* 綠青, *shih lü* 石綠, *thung-lü* 銅綠, *lü khuang* 綠礦), supplemented to some extent by the equally noticeable but less abundant bluish carbonate azurite (*shih chhing* 石青, *tsheng chhing* 曾青, *khung chhing* 空青); cf. Table 6 and Hsia Hsiang-jung *et al.* (*1980*), pp. 20, 245–6. *Tsheng* 曾 stands for *tsheng* 層 'layer, stratum', referring to the tabular crystal form in which azurite frequently appears; Hsia Hsiang-jung *et al.* (*1980*), p. 246; Vol. 5, pt. 2, p. 170, # 53. Likewise, the *khung* in *khung chhing* refers to the hollow spaces or vugs often found in nodular or reniform (kidney-shaped) azurite; Hsia Hsiang-jung *et al.* (*1980*), pp. 246–7.

[31] Hsia Hsiang-jung *et al.* (*1980*), pp. 15; 243. Recall again the comments of F. C. Thompson (1958, p. 1) and R. F. Tylecote (1992, p. 1) on the problem, indeed the impossibility, of using purity of the metal to determine whether an artefact was made of native or smelted copper.

[32] Anon. (*1978b*), p. 10. [33] Bagley (1993). [34] Liu Shizong *et al.* (1993), p. 62.

[35] Muhly has suggested that '[i]t may turn out that the scale of the metal industry will prove to be one of the best indicators of the use of smelted copper.' Muhly (1988), p. 7. This is a very rough rule of thumb, indeed, especially when we are looking for evidence for very early smelting of copper ore. Just how big does a given metal industry have to be before we are justified in concluding that it had to use copper derived from smelting?

[36] Bronson (1993), p. 65.

by analysis of a copper ingot (one of seven found) from a hoard of bronze objects discovered at Kuei-chhih 貴池 county in Anhwei and tentatively dated to the −6th to −5th centuries. Later analyses of copper ingots and slags from neighbouring Thung-ling 銅嶺 have strongly confirmed that sulphide ores, almost certainly chalcopyrites, were regularly used there for smelting copper by the middle of the −1st millennium, making this in all likelihood the pioneering area in China for the smelting of copper sulphide ores.[37] The next clear evidence for the mining of a sulphide ore (chalcopyrite) does not appear until the +1st to +2nd centuries in a cluster of seven mines at Tung-kou 洞溝 in Yun-chheng 運城, Shansi.[38] That these mines were worked for only a short period suggests that use of sulphide ores may still have been economically marginal given the level of contemporary smelting technology. In the following centuries, however, gradual improvements in techniques in calcining (roasting) and smelting made it possible, at least by the Sung, to obtain very pure copper from even low grade sulphide ores. Analysis of Sung coins shows that even those coins produced with copper obtained from iron-rich chalcosite (cf. Table 6) contain little iron, the iron having been successfully removed in the roasting and smelting processes.[39]

(β) *Copper to bronze, bronze to copper*

> The idea of a unified sequence of steps or stages in technological progress – from cold-hammered native copper to the smelting of first simple and then complex copper ores to, finally, the alloying of copper, first with arsenic and then with tin – seems to be gone forever.
>
> *James D. Muhly*[40]

Most of the surviving archaeological evidence suggests that the beginnings of bronze-making in China took place in the north or northwest some time around the beginning of the −2nd millennium. Kho Chün, the respected expert on early Chinese metallurgy, would opt for 'around the −22nd century.'[41] Others would put the date somewhat later, perhaps around the middle of the −2nd millennium.[42] It is now firmly established that areas such as Kansu and Honan, where the earliest bronze objects have been found, were well provided with mixed ores from which tin or lead

[37] Wagner (1993), p. 129; Chang Ching-kuo *et al.* (*1985*); Chhen Jung & Chao Khuang-hua (*1994*). Sulphide ores containing arsenic were being mined and smelted into arsenical bronzes at about the same time at the Nu-la-sai 奴拉賽 mines in Sinkiang; Mei Chien-chün & Li Yen-hsiang (*1995*), *passim*. Increasingly, Chinese scholars seem to be leaning toward the Western Chou (c. −1030 to −722) as the period in which smelting of copper sulphide ores began; see, e.g., Anon. (1994), pp. 26 and 76.

[38] Liu Shizong *et al.* (1993), p. 57; Wagner (1993), pp. 129–31; Barnard (1989), pp. 152–4; An Chih-min & Chhen Tshun-hsi (*1962*), pp. 519, 521; Vogel (1982), pp. 140–1; Hsia Hsiang-jung *et al.* (*1980*), p. 242.

[39] Chao Khuang-hua *et al.* 1986, esp. p. 326, fig. 2. Chalcosite had been mined as early as the Warring States period at Ma-yang in Hunan; cf. Hsiung Chhuan-hsin *et al.* (*1985*).

[40] Muhly (1988), p. 2. [41] Kho Chün (1987), pp. 225–6. For a similar view, cf. Murray (1985).

[42] Hsia Hsiang-jung *et al.* (*1980*), pp. 17, 200; Barnard & Satō (1975), pp. 25–6. One scholar, Thang Lan, has argued a radical position that the Chinese first smelted bronze as early as −4000 and only later learned how to smelt copper. This hypothesis, however, has been carefully examined by An Chih-min, who demolishes it very convincingly by showing that the key artefacts on which it is based are later intrusions. Cf. An Chih-min (*1981*), translated in Murray (1983); and Wen Kuang (*1980*), p. 336.

Table 6. *Main copper ores exploited by the Chinese in traditional times*

Ore type	Mineral (modern term)	Traditional name(s)	Average composition	Max. Cu(%)[a]
Carbonate	Malachite (*khung chhueh shih* 孔雀石)	*lü chhing* 綠青, *shih lü* 石綠, *thung lü* 銅綠, *lü khuang* 綠壙, *hei-lü* 黑綠	$Cu_2[CO_3][OH]_2$	57·5
Carbonate	Azurite (*lan thung khuang* 藍銅壙)	*tsheng chhing* 曾青, *shih chhing* 石青	$Cu_3[CO_3]_2[OH]_2$	55·3
Oxide	Tenorite (*hei thung khuang* 黑銅壙)	*huo yao su* 火藥酥	CuO	79·8
Oxide	Cuprite (*chhih thung khuang* 赤銅壙)	*thung-lo* 銅落	Cu_2O	88.8
Silicate	Chrysocolla (*hsi khung chhueh shih* 矽孔雀石)		$CuSiO_3 \cdot 2H_2O$	36.0
Sulphate	Brochantite (*shui tan fan* 水膽矾)	*pai chhing* 白青, *pi chhing* 碧青, *yü mu chhing* 魚目青	$Cu_4[SO_4][OH]_6$	56.2
Sulphate	Chalcanthite (*tan fan* 膽礬)	*shih tan* 石膽, *tan fan* 膽礬, *tsheng chhing* 曾青	$Cu[SO_4] \cdot 5H_2O$	25·5
Sulphosalt	Bournonite (*chhe lun khuang* 車輪礦)	*pai hsi la* 白錫鑞	$CuPbSbS_3$	13.0
Sulphosalt	Enargite (*liu shen thung khuang* 硫砷銅礦)	*pai hsi la* 白錫鑞	Cu_3AsS_4	48.4
Sulphosalt	Tetrahedrite (*yu thung khuang* 黝銅礦)	*pai hsi la* 白錫鑞	$Cu_{12}Sb_4S_{13}$	23–45
Sulphide	Chalcopyrite (*huang thung khuang* 黃銅礦)	*huang chin po* 黃金箔, *thou shih* 鍮石, *tzu-jan thung* 自然銅	$CuFeS_2$	34·7
Sulphide	Chalcosite (*hui thung khuang* 輝銅礦)	*hsi-la* 錫鑞, *lü hsi la* 綠錫鑞, *hui hsi la* 輝錫鑞	Cu_2S	79·9
Sulphide	Bornite (*pan thung khuang* 斑銅礦)	*tzu chin hsi la* 紫金錫鑞, *hung hsi la* 紅錫鑞	Cu_5FeS_4	63.3

[a] These are theoretical percentages, and not necessarily reflective of the actual Chinese ores.
Based on: Vol. 5, pt. 2, pp. 162–87; Li Chung-chün (*1982*), p. 6; Lung Tshun-ni (*1986*), p. 141; Hsia Hsiang-jung *et al.* (*1980*), pp. 242–51; Dana (1971); Baumann (1976); Emmons (1932), p. 434; Bateman (1950).

bronze could result fortuitously from the smelting process.[43] When we recall what was said above about the frequent presence of tin even in deposits of native copper, it ceases to be surprising that bronze appeared on the scene in China so soon after the Chinese had learned to melt copper and, perhaps, smelt copper ores.[44] Indeed, as suggested by the Ma-chia-yao blade, it may not have been uncommon, depending on the nature of the deposits drawn on, for bronze to have been produced before copper in many areas of China.[45]

For most uses, bronze was superior to copper. The right proportion of tin not only produced a much harder metal but also eliminated or at least mitigated many problems associated with the casting of copper, including its too rapid solidification after heating that made pouring castings difficult, its tendency to shrink away from moulds when cooling, and its absorption of hydrogen that led to hydrogen bubbles in the castings.[46] Indeed, as Barnard and Satō have suggested, it was the dominance of casting in early Chinese metallurgy that put a premium on the advantages of bronze and therefore led to the rapid substitution of bronze for copper in China after at most a very short 'copper age'.[47]

The lavish use of bronze in China by the beginning of the –1st millennium is well attested by the thousands of Shang bronze vessels, weapons and other objects that survive.[48] A particularly dramatic illustration is provided by the contents of a Shang

[43] Rostoker & Dvorak (1991); Murray (1985), p. 264; Li Ching-hua (*1985*), p. 77. The same process may have led later to the discovery of brass; cf. below, Section (*e*)(1)(vi). On the whole question of the smelting of bronze from mixed ores, as well as the presence of these ores in China, cf. Barnard (1989), pp. 188–91; Chhen Jung & Chao Khuang-hua (*1994*), p. 143. Wen Kuang's emphasis on the complete absence in nature of ores with copper and tin together in solid solution (*1980*, pp. 334–6) in no way precludes the possibility that early smelters may have mixed ores of copper and ores of tin that happened to occur near to one another. Clement Reid (as cited in Barnard (1989), p. 199) has provocatively suggested in discussing bronze and tin in early Cornwall (where copper and tin regularly occur together; Shepherd (1993), p. 343) that the re-melting of damaged tools of originally different metallic composition could have produced a mixed metal of a quality superior to the original metals. This could have alerted metal workers to the advantages of mixing ores or metals to form an alloy like bronze.

[44] Thomas T. Read, as early as 1933, stressed the advantages of mixed ores for the development of bronze-making by the Chinese: 'The Egyptians worked in copper for a thousand years or more before they learned to make bronze, while there is evidence that bronze in China goes back almost to the beginning of copper smelting. The obvious reason is that the Chinese had mixed ores to work with, while the copper ore in Sinai was free of other metals, and it was not till the Egyptians began to get tin from a distance that they made bronze.' Read (1933), p. 237.

[45] Barnard's suggestion (Barnard (1989), p. 191) that 'the unintentional alloying of tin–copper bronzes – and, to a greater or lesser extent, the by-passing of a Chalcolithic Age – may well be considered valid as a working hypothesis in the Chinese scene' is worth keeping in mind, especially if we also emphasise that the route to advanced bronze metallurgy need not have been the same for all areas even in northern China.

[46] Patterson (1971), p. 308; Clark (1952), p. 193; Barnard & Satō (1975), pp. 25–6. For certain uses, such as bells, copper could not be used while bronze with the right percentage of tin (15–20%) was ideal; Rostoker *et al.* (1984), pp. 750–1.

[47] Barnard & Satō (1975), p. 26. In the West, even after the availability of bronze, copper continued to be used for artefacts because it was a suitable material for smithy techniques.

[48] As meticulously inventoried in the invaluable Barnard & Satō (1975); an updated version is in preparation. Wagner (1993, p. 11) suggests that, in the Shang and Chou periods together, the total number of bronze ritual vessels produced (therefore *not* including an even larger number of tools and weapons) 'must have been in the tens or hundreds of thousands . . .'. On the other hand, when we speak of the production of the Shang and Chou periods, it is well to remember that we are referring to all the production over more than a thousand years from all the mines and foundries of China. These global figures by themselves, therefore, cannot tell us anything about the general sizes of the mines or foundries that produced them. (See the important cautionary words of Noel Barnard (1989), p. 143, fn. 3.)

royal tomb, that of Fu Hao 婦好 or Lady Hao, wife of King Wu Ting 武丁 (−1334 to −1275).[49] When excavated, the tomb was found to contain more than 200 bronze ritual vessels, the largest of which weighed well over 100 kilograms.[50] It is clear that the major Shang bronzemaking centres at Yen-shih 偃師, Cheng-chou 鄭州 and An-yang 安陽 on the north China plain in present-day Honan, as well as large-scale foundries that are coming to light in south China beyond the area of Shang control,[51] must have consumed very large amounts of copper, and lesser but still substantial amounts of tin and lead.[52] The provenance of all that metal, especially for the bronze industry of north China, is a crucial question for the history of early Chinese mining and metallurgy.

(γ) *The copper and tin deposits of north China*

In seeking out the sources of copper and tin for the north China bronzecasting industry in the Shang, we can begin by asking whether there existed significant deposits of copper and tin reasonably nearby that *could have* provided the Shang bronzemakers with all or most of the metal they needed. Many scholars, including the authors of the only major history of Chinese mining, have denied that this was the case.[53] They have been encouraged in their view by the fact that there is no evidence that the area surrounding the major Shang bronzemaking centres has ever been especially notable for its production of copper and tin. Most of China's copper and tin production right down to the present has been concentrated in the south, including the southeastern coastal region, the Yangtze valley, and the southwest, especially Yunnan (Map 3 and Map 7).[54] It has even been proposed that the central and lower Yangtze region could well have been the area where bronzemaking on any scale in China got its start.[55]

The denial that most of the copper and tin in Shang bronzes could have come from northern mines is undercut, however, by considerable evidence for deposits of copper and tin in north China that have been exploited at one or another time since the Shang, even if not on the scale of the major production centres.[56] Much of this evidence is assembled in two articles from the 1950s, by Amano Motonosuke and

[49] Barnard (1986), pp. 159–63.

[50] Chang Kwang-chih (1980), pp. 88, 151; Chang Kwang-chih (1980a), p. 42.

[51] Cf. Bagley (1993).

[52] Lead, however, was probably not known as a metal in its own right or incorporated intentionally to form a ternary (copper/tin/lead) bronze alloy until late Shang times; Barnard & Satō (1975), p. 100.

[53] Hsia Hsiang-jung *et al.* (*1980*), pp. 198–210; Chang Kwang-chih (1980), p. 151, fn. 78.

[54] Chang Kwang-chih (1980), p. 153; Wei Chou-yuan (1946), p. 451; Hsia Hsiang-jung *et al.* (*1980*), p. 55; Chang Cheng-ming & Liu Yün-thang (*1984*), pp. 70–2. A recently discovered Spring and Autumn period (c. −7th and −6th centuries) inscription from the state of Tseng 曾, which was located south of present-day Sui-hsien 隨縣 in Hupeh, notes that Tseng was a crossroads in the copper and tin trade. Given its location on a logical north/south trade route, this at least suggests the possibility that some copper and tin was moving from south to north China; Zhu Shoukang (Chu Shou-khang) (1986), pl. 8.

[55] Li Hsueh-chhin (*1980*); Chang Ching-kuo *et al.* (*1985*), p. 171, noting that this theory was originally suggested by Kuo Mo-jo. Bagley (1993, p. 36) suggests that trade in copper could help account for both the wealth and the northern contacts revealed by excavations such as that of the habitation site in Hsin-kan 新干 county along the Kan 贛 River in central Kiangsi and dating from the −13th century.

[56] None of the copper deposits worked in traditional times, except perhaps those of Yunnan, would be considered large by modern standards. Moderately large deposits, by contrast, have been fairly numerous; Torgasheff (1930), p. 180. For recent work on China's copper deposits, Kuo Wen-khuei *et al.* (*1978*) and the publications given on p. 180 of that article are a good starting point.

Shih Chang-ju.[57] Both Amano and Shih relied primarily on historical compilations, for the most part from the later imperial period, to construct their lists of sites where copper or tin mining had taken place at any time in Chinese history. Thus they establish at a minimum that the deposits *were present* during the Shang. We shall return to this in a moment. It is important to note here, however, that there were likely still other deposits – how many we cannot say – that have not made their way into the surviving historical sources and whose physical traces have long since been obliterated or covered with loess.[58] The data presented by Amano and Shih has been used and expanded upon in three important monographs, by Ho Ping-ti, Noel Barnard, and Noel Barnard and Satō Tamotsu.[59] We have reproduced here the Barnard and Satō map (Map 4) which conveniently locates each of Shih's copper- and tin-producing sites (except for tin-producing sites more than 400 km from An-yang) and adds two further copper-producing sites since discovered by archaeologists. It does not, however, include the further 13 sites found by Yueh Shen-li.[60]

The picture that emerges from these studies is that there were indeed relatively close (within a radius, say, of 300–400 km) to the major Shang bronze foundries sufficent copper and tin deposits to have provided at least a substantial amount of the metal needed for the industry at that time, especially if, as seems likely, the copper ores were smelted at the mine sites so that only the metal itself was shipped to the foundries.[61] On the basis of his sources, Amano identified 28 copper and 16 tin deposits within a 350 km radius of An-yang.[62] Using Shih's data, Ho Ping-ti has calculated that there were 23 copper and 11 tin deposits within a radius of 300 km of at least one of the three major Shang metallurgical centres. Actually, this probably understates particularly the number of copper 'deposits' since Ho counts each *hsien* mentioned as one deposit though Shih's list makes clear that many *hsien* had two or

[57] Amano (*1953*) and Shih Chang-ju (*1955*). The two scholars obtained their data independently but Shih was able to check his results against Amano's before publishing and found them to be 'substantially the same.' Shih Chang-ju (*1955*), p. 104, n. 1. Actually, Shih casts his net much more widely and does not limit himself, as did Amano, to sites within 300 km of An-yang. His is therefore a much more complete overview of copper and tin deposits known in traditional China. Moreover, though they do not appear on his list, Shih also gives in a footnote a further 13 copper-producing sites identified by Yueh Shen-li 岳慎禮 in an article that appeared after Shih had completed his study; Shih Chang-ju (*1955*), p. 100, fn. 1.

[58] Similarly, there is no longer tin to be mined in the Caucasus area of Europe though there may well have been in earlier times; Shepherd (1980), p. 169. By contrast, China still has more than 800 copper ore deposits broadly distributed over 27 provinces; Zhu Shoukang (Chu Shou-khang) (1986), p. 6; Gan (1994), book 1, p. 12.

[59] Ho Ping-ti (1975); Barnard (1961); Barnard & Satō (1975).

[60] See note 57. By discussing both copper and tin deposits here, we are to some extent 'jumping the gun' on the following section, which focuses on tin. Since the main research we draw on, however, has discussed these deposits together, using the same methodology and similar kinds of evidence, it seemed preferable to treat them together here.

[61] Ho Ping-ti (1975), pp. 189–90; Barnard (1961), p. 49; Barnard & Satō (1975), p. 22, fn. 35 and p. 26. For trade over similar distances in the north China area as early as the end of the Pleistocene period (c. −10000), see Cheng Te-khun 1959, p. 37. For the trade in copper and tin in Bronze Age Europe, see Muhly (1987), especially p. 106, which argues for a relatively late rise of a bulk trade in raw copper that helps to account for the later and smaller bronze industry of copper-poor Cornwall ('. . . England [and Cornwall] lacked . . . rich sources of copper') by comparison with that of central Europe with its abundant copper deposits. Muhly may mean copper resources that were exploitable in a Bronze Age context. After all, out of an estimated world production (excluding China) of copper totaling 10,000 tonnes around +1800, the copper mines of Cornwall accounted for some 7,000 tonnes; Vogel & Theisen-Vogel (1991), pp. 9, 14.

[62] Amano (*1953*), pp. 233–5.

Map 4. The distribution of known and recorded copper and tin ore locations in relation to An-yang, after Shih Chang-ju with two further sites (nos. 125 and 126) added. Barnard & Satō (1975), pp. 24–5. No tin sites beyond a 400 km radius are included. For 13 more tin deposits in Shantung, Honan south of the Yellow River, and Shensi, see Wen Kuang (1980), pp. 425–7.

Copper ore locations (●)

3,000 km or more	1.	Ho-thien	和闐	新疆西部
	2.	Yeh-chheng	葉城	"
	3.	Shu-fu	疏附	"
	4.	Wu-shih	烏什	"
3,000–2,000 km	5.	Wen-su	溫宿	"
	6.	Pai-chheng	拜城	"
	7.	Fu-chü	庫車	"
	8.	Yen-chhi	焉耆	"
	9.	Yi-li (Sui-ting)	伊犁	(綏定)
	10.	Ti-hua	迪化	
2,000–1,500 km	11.	Yen-chi	延吉	松江
	12.	Yang-chiang	陽江	廣東
	13.	Yü-lin	鬱林	廣西
	14.	Thien-pao	天保	"
	15.	Ssu-mao	思茅	雲南
	16.	Pu-erh	普洱	"
	17.	Chien-shui	建水	"
	18.	Chheng-chiang	澂江	"
	19.	Khun-ming	昆明	"
	20.	Lo-tzhu	羅次	"
	21.	I-men	易門	"
	22.	Meng-hua	蒙化	"
	23.	Pao-shan	保山	"
	24.	Ta-li	大理	"
	25.	Yung-sheng	永勝	"
	26.	Hui-li	會理	西康
	27.	Yen-yuan	鹽源	"
	28.	Thung-phu	同普	"
1,500–1,000 km	29.	Lin-hai	臨海	浙江
	30.	Min-hou	閩侯	福建
	31.	Phu-thien	莆田	"
	32.	Kung-hsien	贛縣	江西
	33.	Lien-hsien	連縣	廣東
	34.	Yung-hsing	永興	湖南
	35.	Kuei-yang	桂陽	"
	36.	Chhang-ning	常寧	"
	37.	Chhi-yang	祈陽	"
	38.	Shao-yang	邵陽	"
	39.	Hsin-ning	新寧	"
	40.	Sui-ning	綏寧	"
	41.	Hui-thung	會同	"
	42.	Ma-yang	麻陽	"
	43.	Cheng-an	正安	貴州
	44.	Chih-chin	織金	"
	45.	Pi-chieh	畢節	"
	46.	Phan-hsien	盤縣	"
	47.	Wei-ning	威寧	"
	48.	Hui-tse	會澤	雲南
	49.	Chhiao-chia	巧家	"
	50.	Hsi-chhang	西昌	西康
	51.	Pheng-hsien	彭縣	四川
	52.	Te-ko	德格	西康
	53.	Le-tu	樂都	青海
	54.	Ku-lang	古浪	甘肅
	55.	Khai-yuan	開源	遼北
	56.	Phan-shih	盤石	吉林
	57.	Hua-tien	樺甸	"
	58.	Thieh-ling	鐵嶺	遼寧
	59.	Fu-shun	撫順	"
	60.	Lin-chiang	臨江	安東
	61.	Huan-jen	桓仁	"
	62.	Kuan-tien	寬甸	"
1,000–500 km	63.	An-tung	安東	"
	64.	Feng-chheng	鳳城	"
	65.	Pen-hsi	本溪	遼寧
	66.	Liao-yang	遼陽	"
	67.	Kai-ping	蓋平	"
	68.	Hsing-chheng	興城	"
	69.	Sui-chung	綏中	"
	70.	Kou-jung	句容	江蘇
	71.	Chiang-ning	江寧	"
	72.	Tang-thu	當塗	安徽
	73.	Hsuan-chheng	宣城	"
	74.	Ning-kuo	寧國	"
	75.	Fan-chhang	繁昌	"
	76.	Nan-ling	南陵	"
	77.	Chhing-yang	青陽	"
	78.	Ta-yeh	大冶	湖北
	79.	Yang-hsin	陽新	"
	80.	Liu-yang	瀏陽	湖南
	81.	Hsiang-than	湘潭	"
	82.	Chhen-hsi	辰谿	"
	83.	Yuan-ling	沅陵	"
	84.	Thao-yuan	桃源	"
	85.	Shih-men	石門	"
	86.	Ta-yung	大庸	湖南
	87.	Sang-chih	桑植	"
	88.	Hsien-feng	咸豐	湖北
	89.	Ho-feng	鶴峰	"
	90.	En-shih	恩施	"
	91.	Chien-shih	建始	"
	92.	Fang-hsien	房縣	"
	93.	Chu-shan	竹山	"
	94.	Chen-an	鎮安	陝西
	95.	Ching-yuan	靖遠	甘肅
	96.	Yung-teng	永登	"
500–400 km	97.	Hsin-yang	信陽	河南
	98.	Fu-hsien	鄜縣	陝西
400–300 km	99.	Wan-hsien	完縣	河北
	100.	Po-shan	博山	山東
	101.	Lai-wu	萊蕪	"
	102.	Thung-shan	銅山	江蘇
	103.	Hsieh-hsien	解縣	山西
	104.	Phing-lu	平陸	"
300–200 km	105.	Chi-nan	濟南	山東
	106.	Lu-shan	魯山	河南
	107.	Yü-hsien	禹縣	"
	108.	Teng-feng	登封	"
	109.	Yuan-chhü	垣曲	山西
	110.	Hsia-hsien	夏縣	"
	111.	Wen-hsi	聞喜	"
	112.	Chiang-hsien	絳縣	"
	113.	Chhü-wo	曲沃	山西
	114.	I-chheng	翼城	"
	115.	Thai-yuan	太原	"
200–100 km	116.	Nei-chhiu	內邱	河北
	117.	Hsing-thai	邢臺	"
	118.	Sha-ho	沙河	"
	119.	Chi-yuan	濟源	河南
	120.	Yang-chheng	陽城	山西
	121.	Lu-an	潞安	"
100 km or less	122.	She-hsien	涉縣	河南
	123.	Li-chheng	黎城	山西
	124.	An-yang	安陽	河南
	125.	Thang-yin	湯陰	"
	126.	Yun-chheng	運城	山西

Tin ore locations (▲)

100 km or less	A.	Chhi-hsien	淇縣	河南
	B.	Chheng-an	成安	河北
	C.	Kuang-phing (Chhi-hsien)	廣平 (磁縣)	"
	D.	Wu-an	武安	河南
101–200 km	E.	Yang-chheng	陽城	山西
	F.	Chhin-yuan	沁源	"
	G.	Chhin-shui	沁水	"
201–300	H.	Ju-chou	汝州	河南
	I.	Lai-wu	萊蕪	山東
	J.	Chiao-chheng	交城	山西
	K.	Sung-hsien	嵩縣	河南
301–400 km	L.	Yung-ning	永寧	"
	M.	Ling-pao	靈寶	"
	N.	Phing-lu	平陸	山西
	O.	An-i	安邑	"
	P.	I-hsien	嶧縣	山東
	Q.	Fang-chheng	方城	河南

more copper mines or mining areas.[63] Moreover, new deposits are still being found. In a recent article, Li Ching-hua (Li Jinghua) gives a total for Honan alone of 29 copper mines, 27 lead/tin mines and 8 tin mines, most of which were known in early times.[64]

We should also not lose sight of the likelihood that some of these deposits were quite rich, even if they were not very large. For instance, in 1919, copper mining in Chi-yuan 濟源, Honan, just over 160 km southwest of An-yang as the crow flies, could draw on ore containing between 5 and 20 per cent copper and produce one tonne of copper per year.[65]

Chang Kwang-chih may also be right when, in a speculative but highly suggestive article, he stresses the dependence of political power on bronze technology and argues that the relocations of secular capitals (*su-tu* 俗都) in the Hsia, Shang and early Chou periods had as one of their important motivations the desire of the rulers to have their capital closer to copper and tin deposits, especially those of southern Shansi and northern Honan.[66] Nevertheless, as he himself has noted, all of the above evidence can prove only that the necessary metals were available in north China deposits.[67] We have as yet no archaeological evidence on actual Shang copper (or tin) mines in north China (cf. Map 5).[68] Furthermore, because many – probably even most – of the deposits from which the copper came have undoubtedly long been exhausted and because the extreme diversity of impurities in smelted copper makes the tracing of copper or bronze or slag to an original deposit very difficult,[69] evidence linking copper or bronze objects from early China to specific deposits has been slow to appear.[70]

This, however, is changing, at least in one area of research. Lead isotope studies in China, Japan and the United States have now provided a significant body of data that seems to establish beyond question that *some* of the metal used in Shang and

[63] Ho (1975), pp. 184–5. Ho agreed with Shih (pp. 102, 104) on the likelihood that southern Shansi, with its rich copper deposits together with deposits of tin, might have been the chief source of metals in the Shang (p. 186). Other possibly important supply centres could have been: Lai-wu 萊蕪 in Shantung for which we have evidence from the Thang on the production of copper and tin (Amano (*1953*), p. 234) and Thung-shan ('Copper Mountain') chen 銅山鎮, a mere 20 km from Hsiao-thun 小屯 and known for its native copper (Shih Chang-ju (*1955*), pp. 99, 102).

[64] Li Jinghua (1993), pp. 21–2. Zhu Shoukang (Chu Shou-khang) presents a total of more than 800 known copper deposits in the 27 provinces of China and says that 'most of them produced copper in ancient times'. Zhu Shoukang (1986), p. 6. His 'ancient' is probably meant to be taken very broadly, perhaps meaning the entire pre-19th century period.

[65] Amano (*1953*), p. 234.

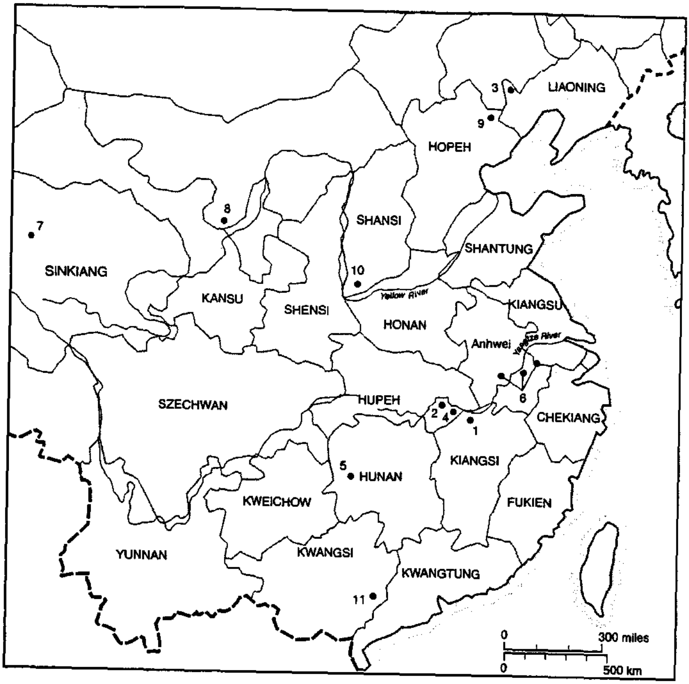
[66] Chang Kwang-chih (*1985*), p. 64. Ho Ping-ti has suggested that Shang military campaigns, especially in Shansi, very probably were motivated by a desire to gain or safeguard control over that metal-rich area; Ho (1975), p. 187 and Shih Chang-ju (*1955*), p. 103. (The Hoovers argue that the same motivation helps account for the extent and borders of the Roman Empire: Hoover & Hoover (1912), p. 83.) Since southern Shansi, apart from its metals, was also an important source of lake salt, that may also have attracted Shang military incursions. Cf. the interesting discussion in the *Tso Chuan*; Legge (1872), p. 360. (I am indebted to Hans Ulrich Vogel for reminding me of this reference.)

[67] Chang Kwang-chih (1980), p. 153.

[68] Many, of course, probably lie under deep deposits of loess. Nevertheless, it is likely that Shang mines will eventually be found. One possible Shang mining site is Lin-ju hsien 臨汝縣 in Honan. Copper smelting seems to have been carried on here before –2000 and ancient workings have been discovered at two copper mines to the northeast of the city, though they have not yet been dated. Cf. Li Ching-hua (*1985*), p. 75.

[69] Aitchison (1960), p. 176; Muhly (1988), p. 7.

[70] A similar difficulty is met with when bronze artefacts are discovered at a particular site. Without other archaeological or textual evidence (e.g. traces of a foundry or inscriptions on the objects), we cannot know where the objects were cast and still less the provenance of the metals that went into them.



Map 5. Sites of excavated pre-Han and Han copper mines (numbered in rough chronological order according to when mining seems to have begun).

1 Kiangsi: Jui-chhang shih 瑞昌市, Thung-ling 銅嶺 (mid-Shang-late Spring and Autumn)
2 Hupeh: Huang-shih shih 黃石市, Thung-lü shan 銅綠山 (Shang(?)/Western Chou-Han)
3 Inner Mongolia: Lin-hsi hsien 林西縣, Ta-ching 大井 (late Western/early Eastern Chou; radiocarbon dates in the 2900 to 2700 BP range)
4 Hupeh: Yang-hsin hsien 陽新縣, Kang-hsia 港下 (late Western/early Eastern Chou; radiocarbon date 2875 ± 80 BP)
5 Hunan: Ma-yang hsien 麻陽縣 (late Western/early Eastern Chou; radiocarbon date 2730 ± 90 BP)
6 Anhwei: Thung-ling hsien 銅嶺縣, Nan-ling hsien 南嶺縣, Kuei-chhih hsien 貴池縣, Chhing-yang hsien 青陽縣 and others (late Western Chou to Sung; radiocarbon dated to −9th century)
7 Sinkiang: I-li 伊犁, Ni-lo-kho 尼勒克, Nu-la-sai 奴拉賽 (Western/early Eastern Chou; radiocarbon date 2650 ± 170 BP)
8 Ninghsia: Chao-pi shan, Chung-wei hsien 中衛縣 (early Eastern Chou – Yuan)
9 Hopeh: Chheng-te 承德 Chuan-chü (Han, possibly Western Han)
10 Shansi: Yun-chheng 運城, Tung-kou 洞口 (Western/Eastern Han, Three Kingdoms, Chin)
11 Kwangsi: Pei-liu hsien 北流縣, Thung-shih ling (Han; radiocarbon date 1910 ± 90 BP)

Based on Liu Shizong *et al.* (1993); Barnard (1989); Lu Pen-shan (*1990*); Vogel (1982); Li Thien-yuan (*1988*); Yang Li-hsin *et al.* (*1989*). Radiocarbon dates from Liu Shizong *et al.* (1993), which draws heavily on Chou Wei-chien *et al.* (*1990*).

Western Chou bronzes came from deposits in Thung-lü shan 銅綠山, south of the Yangtze in central China, and even from as far away as northeastern Yunnan.[71]

Where then does that leave the question at present? Given a significant level of trading contacts between north and south China during the Shang,[72] we should not be surprised if metals played a rôle in that trade. On the other hand, it is very hard to imagine that the vast amounts of copper needed by the northern Chinese bronze foundries could have been met mainly by metal imports from southern and south-western mines more than 400 km distant. And is it likely, given the sophistication of Shang metallurgical technology, that mining knowledge and technology lagged so far behind that of metallurgy that the people of north China in the Shang were unable to exploit relatively abundant nearby deposits of copper and tin and instead had to rely on imports from more distant areas in south China?[73]

Moreover, as we have noted above, a flourishing bronze industry existed in south China by the end of the −2nd millennium.[74] At the present time, the evidence is still insufficient to establish (1) a diffusion of bronze technology in China from north to south, or (2) from south to north, or (3) derivation of both the northern and southern bronze traditions from an as yet unknown third and earlier bronze tradition, or (4) independent discovery of bronze in both north and south China and mutual interaction between the two. What the recent discoveries of extensive bronze casting in south China do suggest, however, is that demand for copper and tin must have been quite strong there during the Shang period.[75] This makes it still more unlikely that large amounts of southern metals made their way north to feed the foundries of the Shang.

(δ) *Pre-Han copper mining sites*

The vigorous and growing demand for copper from at least the middle of the −2nd millennium led to the emergence of copper mining and smelting as China's first large-scale metals industry. It is therefore not entirely by accident or particularly surprising that all the pre-Han mines so far discovered and excavated in China have been copper mines (Map 5).[76] The two earliest and most remarkable sites both occur in the central Yangtze region, just south of the river itself.

71 Wagner (1993), p. 19; Chin Cheng-yao (*1990*); Li Hsiao-tshen (*1993*).

72 Amano (*1953*), pp. 231–2; Shih Chang-ju (*1955*), p. 102; Zhu Shoukang (1986), p. 8; Li Hsiao-tshen (*1993*), pp. 266–7.

73 As argued in Hsia Hsiang-jung *et al.* (*1980*), pp. 198–9 or in Thung En-cheng (*1990*).

74 And in Yunnan, too. See Meacham (1977), p. 438; Chin Cheng-yao (*1990*), p. 289. In all likelihood, however, this was related to the emergence of copper and bronze cultures in southeast Asia rather than to developments in other parts of China.

75 See, for example, Bagley (1980) and (1993).

76 In addition to the works cited below, I have greatly benefited when revising this section for the final draft from two as yet unpublished articles by Noel Barnard: 'The Origin, Development, and Spread of Metallury in Ancient China' and 'The Ancient Copper Mines of Thung-ling, Jui-chhang, Chiang-hsi' in which, especially in the second of the two (written in collaboration with Hua Chueh-ming, Liu Shih-chung and John Head), these early mining sites are described in more detail than we could go into here. I wish to express my thanks to Dr Barnard for providing me with copies of these two drafts as well as for much other assistance in the course of this project. In addition, just as I was completing this final draft, my attention was drawn by Emma Bunker to a notice by Wang Feng (*1995*, p. 660) concerning the accidental discovery by peasant miners in 1984 of the remains of two probably Warring States gold mines in Hsing-lung 興隆 hsien, Hopeh. Despite the fact that the discovery was made more than ten years earlier, Wang's notice seems to be the first information on it to appear in print. Both mines seem to have been opencast trenching operations extending to a maximum depth of about 3 m with widths

Thung-ling 銅嶺

The Thung-ling mines, 100 to 200 m above sea level on the slopes of Ho-lien 合連 and Thieh-shan 鐵山 mountains outside of Jui-chhang 瑞昌, were first discovered by local villagers in the course of road construction in 1988. In contrast to events at Thung-lü shan 銅綠山, where a significant part of the remains were destroyed in the course of the mining operations that led to their discovery, at Thung-ling steps were rapidly taken by several levels of authorities to establish a preservation zone (*pao-hu fan-wei* 保護範圍) around the remains and to initiate immediate excavation by archaeologists. The Chinese now point to this effort as a model for the preservation of cultural artefacts.[77]

The chronological picture at Thung-ling, based especially on the well-preserved stratigraphical sequence, on analysis of pottery shards and on radiocarbon readings, seems quite clear. Mining began here probably at least by the middle of the Shang dynasty (c. −1300), flourished especially in the Spring and Autumn period (c. −8th to −5th centuries) and eventually came to an end in the following Warring States period.[78]

The kinds of conditions that encouraged the early appearance of a major mining industry at Thung-ling could be found in most of the other early mining centres in the middle and lower Yangtze area: rich oxide ores (malachite and azurite)[79] together with native copper in a contact zone where the friable rock made mining relatively easy, well-developed nearby agriculture as well as rich forests that could provide the food and timber supplies necessary to support a major mining operation, and access to relatively good transportation (only 6 km from the nearest point on the south bank of the Yangtze).[80]

The ancient mining sites cover an area of 4,000 to 5,000 square m.[81] According to the most recent reports, 1,800 square m of surface mines and 1,200 square m of underground mining have been excavated.[82] The latter include 120 shafts and 18 drifts.[83] The early examples of timbering here, which date from perhaps the −14th century, predate any such remains elsewhere in China.[84]

Thung-lü shan 銅綠山

The first large-scale early copper mine to be discovered and reported on was Thung-lü shan near Ta-yeh 大冶 in Hupeh (and only about 100 km southeast of Thung-ling). Objects found in this area since 1959 had hinted at ancient remains but it was

from 0.5 m to 1.0 m. The longer of the two trenches was about 30 m, the shorter 20 m. Finally, for the latest information as this volume went to press on all of the sites described below, see Su Jung-yü *et al.* (*1995*), a copy of which Su Jung-yü generously presented me with but unfortunately too late to make more than cursory use of for this study.

77 Chou Wei-chien *et al.* (*1990*), p. 13.

78 Pheng Shih-fan & Liu Shih-chung (*1990*), pp. 25–6; Chhen Jung & Chao Khuang-hua (*1994*), pp. 139–40. Fourteen radiocarbon assessments have recently been completed by the Australian National University Radiocarbon Dating Laboratory (1995); according to a personal communication from Noel Barnard, the earliest date to result was around −1220 (3170±80 BP).

79 Average copper content of 5–6%, sometimes as high as 10–20%; Lu Pen-shan & Liu Shih-chung (*1993*), p. 33.

80 Chou Wei-chien *et al.* (*1990*), p. 21.

81 Lu Pen-shan & Liu Shih-chung (*1993*), p. 33 (4,000 sq. m); Chou Wei-chien *et al.* (*1990*), p. 18 (5,000 sq. m).

82 Lu Pen-shan & Liu Shih-chung (*1993*), p. 33.

83 Hua Jueming (1994), p. 1.

84 Chou Wei-chien *et al.* (*1990*), p. 20. On these mines, see also Anon. (*1990*).

the inauguration of modern open-pit operations in 1965 that first uncovered ancient mine shafts. The discovery in 1973 of what appeared to be a bronze axehead (now thought to have been a gad or chisel (*tsao* 鑿)) suggested that the earlier workings were older than had previously been thought, and excavations began in earnest.[85]

The scope of these ancient workings, the largest yet found in China, is astonishing: over an area roughly 2 km north/south and 1 km east/west, archaeologists have discovered seven open-pit operations, 18 underground stopes created by the removal of some 1,000,000 cubic m of earth and stone, and 252 shafts (of which 93 have been excavated).[86] The shafts, together with nearly 100 galleries, have a total length of over 8 km.[87] Remains of over 50 smelters have been identified and a stratum of smelting slag covers some 140,000 square m, sometimes to a thickness of 3 m. It is estimated to total up to 600,000 tonnes from which at least 40,000 and perhaps as much as 120,000 tonnes of copper were produced, though the latter figure is almost certainly too high.[88]

Although significant underground mining may not have begun at Thung-lü shan until somewhat later than at Thung-ling, it then seems to have been carried on, though perhaps intermittently, for the better part of a millennium. That this was possible reflects the considerable size of the deposit suitable for exploitation by traditional techniques. Thus we have in Thung-lü shan a mining complex that was in operation throughout the Chinese transition from the bronze to the iron age.[89]

[85] Hsia Nai and Yin Wei-chang have provided a concise summary of the areas excavated in 1974 and in 1979–1980, as well as perhaps the best and most careful synthesis of what has been learned from the excavations. (Hsia Nai & Yin Wei-chang (*1982*), p. 1.) There is a large literature on Thung-lü shan. Besides the above article, I have found most helpful the following: Lu Mao-tshun (*1974*) (the first substantial report on the excavations, translated not very satisfactorily in Buck (1975)); Anon. (*1975*); Yeh Chun (*1975*); Anon. (1980) (containing a short overview of the excavations and what we have learned from them, in Chinese and in English, with excellent illustrations); Anon. (*1981*); Yang Yung-kuang *et al.* (*1980–1981*) (many illustrations that tend, however, to give an idealised picture of the mining operations); Chou Pao-chhüan (*1984*); Li Thien-yuan (*1988* and *1988a*) (very good on wall and roof supports, together with discussion of other more recently discovered and sometimes better preserved mines in the area of, and contemporary with, Thung-lü shan). See also Chang Cheng-ming & Liu Yü-thang (*1984*); Lu Pen-shan (*1985*); Chu Shou-khang (*1985*); Chu Shou-khang & Han Ju-pin (*1986*); Chu Shou-khang & Chang Wei-shai (*1986*). In Western languages, apart from Anon (1980), there are Hsia & Yin (1982) (an English summary of Hsia Nai & Yin Wei-chang (*1982*)); Zhou Baoquan *et al.* (1988), Barnard (1989), pp. 168–86 and Vogel (1982) (all with illustrations). Wagner (1986) deals mainly with smelting but also contains information on mining.

[86] Vogel (1991), p. 155; Barnard (1989), p. 173. (Chou Pao-chhüan (*1984*), p. 67 gives a total of 400+ shafts and galleries.)

[87] The Tung-lü shan mining complex appears then to have been far smaller than, for example, Laurion in Greece, with its 2000+ shafts, more than 140,000 m of tunnels and perhaps as many as 20,000 slaves working the mines at their peak production in the −5th century; Barnard (1989), p. 176, fn. 21; Forbes (1963), p. 196; Shepherd (1993), p. 61. On the other hand, the two sites appear to be roughly comparable in their level of technical achievement.

[88] Wagner 1986, p. 2; Ho Ping-chang (*1984*), p. 643; Yang Yung-kuang *et al.* (*1980–1981*), p. 84; Li Chung-chün (*1982*), p. 1; Anon. (1980), n.p.; Chou Pao-chhüan (*1984*), p. 69. By way of comparison, it has been estimated that, in the eastern Alps between −1300 and −800, some 20,000 tonnes of copper were produced; Forbes (1954), pp. 586–7.

[89] Some Chinese scholars would argue for a still earlier beginning of copper mining at Thung-lü shan. Though most of the radiocarbon dates cluster in the three centuries between −880 and −580, at least three timber samples have radiocarbon dates and dendrochronologically calibrated dates that suggest mining some five hundred years earlier, in the mid-Shang. Cf. Wagner (1986), p. 2 and especially p. 3, table 1 and p. 4, table 2; Yang Yung-kuang *et al.* (*1980–1981*), p. 84; Vogel (1991), p. 155. This interpretation gains further support from the fact that, as Yang Yung-kuang, Li Chhing-yuan and Chao Shou-chung point out, shafts that they take to date from the second half of the Shang are driven through previously excavated rock, suggesting open-pit mining on a large scale still earlier; Yang Yung-kuang *et al.* (*1980–1981*), p. 87. On the other hand, no clearly Shang artefacts have yet been discovered at Thung-lü shan, nor is there any clear stratigraphic evidence for mining here in the Shang; Pheng Shih-fan & Liu Shih-chung (*1990*), p. 31, n. 17. (The same holds true for the Chiang-mu-chhung 江木冲 site in southern Anhwei, for which see below.) Chou Pao-chhüan, Hu Yu-yen and Lu Pen-shan accept on the

Because of the long period over which mining was carried on, we can study at Thung-lü shan a phenomenon characteristic of the history of mining: workings that, wholly or partly because of technological limitations, are given up in one period can be reopened and reworked in a later period when technological advances make that technically and/or economically feasible.[90]

Most of the Thung-lü shan ore bodies, which outcropped at the surface or were covered with only a light overburden, lay in a granite–marble and granodiorite–porphyry contact zone where (1) some of the shallower parts of the copper pyrite intrusion underwent oxidation to produce the copper oxides, cuprite (ruby copper) and tenorite; (2) copper sulphates produced by erosion of the intruded copper pyrites reacted with limestone to produce the copper carbonates malachite and azurite; and (3) the hydrated iron oxide limonite produced by the erosion of iron pyrites that were also present in the original intrusion reacted with the copper sulphates to produce native copper, mainly in the form of granules (cf. Table 6).[91] Long weathering of the ore bodies had produced a rich oxidation zone that reached depths of 30–100 m.[92] All 11 of the ore bodies present at Thung-lü shan had been discovered and worked by the ancient miners.[93] Since much of the rock in the fracture zone was friable, these were in many ways ideal deposits for exploitation with primitive mining tools and techniques. Less favourably, the friable rock required considerable support to protect underground workings against collapse (cf. (*h*)(4) below).[94]

The ores worked at Thung-lü shan typically yielded after dressing 12–20 per cent copper and about 30 per cent iron. In the pre-Han period, however, they were never worked for iron.[95] The Thung-lü shan miners were fortunate in being able to exploit a zone of oxidised deposits which, because of long weathering, reached depths of anywhere from 30 to 100 m.[96] Thus they did not have to contend with sulphide ores.[97]

Not only the rich ore deposits but also the location of Thung-lü shan must have greatly encouraged its development as a mining centre. Lying only 20 km south of the Yangtze and connected to it by water, it had relatively easy access to two of the major cities of south China during the Chou, nearby O-chheng 鄂城 and the more

basis of the radiocarbon dates *and* the identification of pottery shards that mining began here 'in the early Western Zhou Dynasty (eleventh century B.C.)'; Zhou Baoquan *et al.* (1988), p. 125. At least a small amount of mining seems to have been carried on as late as the Thang and Sung.

[90] This is true not only of mining but also of smelting, where earlier slags can be resmelted for remaining minerals that could not be extracted with more primitive techniques.

[91] Vogel (1982), p. 146; Barnard (1989), p. 185; Anon. (*1975*), p. 10; Hsia Nai & Yin Wei-chang (*1982*), p. 2.

[92] Chou Wei-chien *et al.* (*1990*), p. 21; Hsia Hsiang-jung *et al.* (*1980*), p. 254.

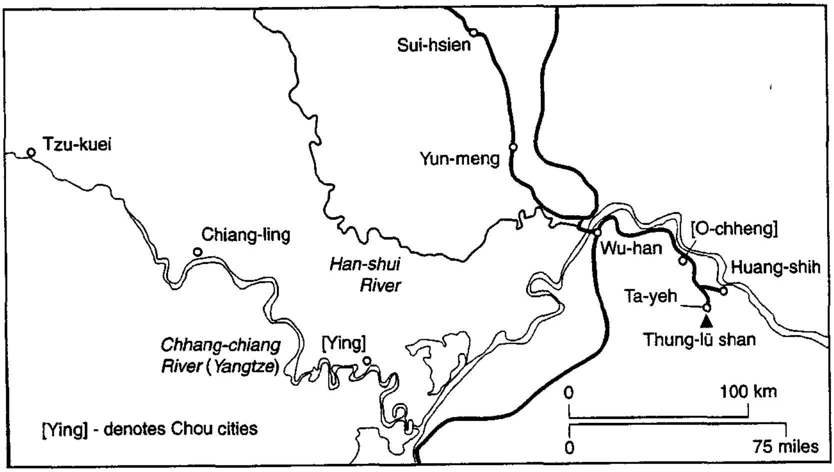
[93] Chou Wei-chien *et al.* (*1990*), p. 18.

[94] It is estimated that 3,000 cubic m of wood were used in the timbering discovered by 1980; Yang Yung-kuang *et al.* (*1980–1981*).

[95] Wagner (1986), pp. 3–4, 10; Barnard (1989), p. 185. Even in the Sung, the miners seem to have been uninterested in the iron; Zhu Shoukang (1986), p. 7, table 6. Nodular malachite, which was probably the most sought-after ore, could have a copper content ranging from 20% to 57%; Hsia Nai & Yin Wei-chang (*1982*), p. 1. For a clear, colour photograph of an ore basket found filled with malachite, cf. Anon. (1980) (no page or plate numbers).

[96] Chou Wei-chien *et al.* (*1990*), p. 21. Donald Wagner has referred to these deposits as 'a geological freak' because of the amount of workable oxide ore; Wagner (1993), p. 129. Inefficient smelting of these rich oxide ores in early times could leave behind *slags* with a higher metal content than that found in most of the *ores* the copper industry relies on today; Read (1933), p. 253.

[97] At the bottom of the old workings, enriched deposits of soft native copper and malachite are still present; Hsia Hsiang-jung *et al.* (*1980*), p. 244.



Map 6. Thung-lü shan 銅綠山 and its surrounding region. Based on Anon. (1980), n.p., supplemented.

distant Ying 郢, which served as the capital of the state of Chhu 楚 for more than four centuries from −689 until its destruction in −278 (Map 6). Good transportation in the area facilitated the supply of provisions for the miners. It also assured that the necessary wood for mine supports and to serve as a fuel for smelting could be brought in from the surrounding rich forests that thrived in the mild, wet central Yangtze climate.[98]

Because of the scale and variety of the underground workings, Thung-lü shan is the earliest surviving mining site so far excavated and reported on to give us a good picture of the emergence and development of all the major underground mining techniques: support of walls and roofs, lighting, ventilation, haulage and hoisting, and water management.[99] In particular, we are fortunate that '[t]he wooden and bamboo structures have survived because they were 'pickled' in the copper-salt-bearing water.'[100] We shall refer to it often in the following pages.

Here, we might simply emphasise that the knowledge of early Chinese mining technology that these excavations have provided far surpasses anything that can be learned from the scanty surviving written sources. For example, we can trace the development of excavation techniques from open pit mining to the use of vertical shafts because of masses of rock (in one area, more than 200,000 cubic m) accumulated from early open pit workings that later had vertical shafts driven through them, as was noted above. Because of the relatively sophisticated level of technology reached here, Thung-lü shan can also serve as a benchmark by which to measure the

[98] Yang Yung-kuang *et al.* (*1980–1981*), p. 85.
[99] Increasingly, it will share this honour with the Thung-ling mines of Jui-chhang.
[100] Zhou Baoquan *et al.* (1988), p. 125.

level of technique of contemporary mines elsewhere in China as well as later mines, many of which fell far short of the best standards achieved at Thung-lü shan.[101]

The Ta-ching 大井 *mines, Lin-hsi* 林西 *hsien, Inner Mongolia*

These mines were discovered in 1974 not far from the upper reaches of the Hsi-la-mu-lun 西拉木倫 River.[102] The more than 45 surface workings over an area of some 2.5 square km represent the best example yet found in northeast Asia of large-scale primitive open-pit mining with stone tools.[103] The workings were in the form of trenches that followed outcrops of seams, of which there were one hundred or more.[104] The longest was over 500 m in length, with a depth of 10 m and a width narrowing down to as little as 0.6 m![105] Radiocarbon tests show that mining began here at least by the early part of the –1st millenium.[106]

Kang-hsia 港下

The Kang-hsia mining site lies only a few dozen kilometres southeast of Thung-lü shan 銅綠山 and borders on Jui-chhang 瑞昌 to the south. The Chinese archaeologists have tentatively dated these mines as late Western Chou, that is, in the –9th or –8th century, or perhaps somewhat later, though a single radiocarbon date, when calibrated, suggests possibly an even earlier dating.[107] Because present-day mining at this site is small-scale and only minimally mechanised, little damage was done except to the very uppermost levels of the remains before formal excavations were carried out (1985–1986). The site is particularly interesting for the timbering methods used; these will be discussed below (Section (*h*)(4)).

The Ma-yang 麻陽 *mines of western Hunan*

The remains of one surface and 14 underground workings in a sedementary sandstone deposit were discovered in 1979 and 1982 some 32 km northeast of Ma-yang

[101] For example, Yang Yung-kuang, Li Ching-yuan and Chao Shou-chung claim that the timbering techniques worked out here by the Western Han period are essentially comparable with wooden timbering as used in contemporary China; Yang Yung-kuang *et al.* (*1980–1981*), p. 90.

[102] Chin Tien-shih *et al.* (*1983*); Barnard (1989), pp. 166–8; Tu Fa-chhing & Kao Wu-hsun (*1980*), pp. 93–4; Liu Shizong *et al.* (1993), p. 58; Chou Wei-chien *et al.* (*1990*), p. 18; Zhu Shoukang (1986), p. 9.

[103] Over 1,500 stone implements, made from a granite and basalt conglomerate, were excavated at these mines; Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 93; Zhu Shoukang (1986), p. 9.

[104] Chin Tien-shih *et al.* (*1983*), p. 144; Barnard (1989), p. 166.

[105] The average depth of the trenches was 7–8 m, with the deepest reaching a depth of 17 m; Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 94.

[106] Barnard (1989), p. 168.

[107] Li Thien-yuan (*1988*); Vogel (1991), p. 162. Vogel makes some important comments here about why the dates suggested in the Chinese reports of mining excavations are not always as well founded as they might seem at first sight. Thus, contrary to a common preconception of the excavators, the sophistication and strength of the timbering methods used may be less an indication of chronological evolution (with more 'primitive' methods always associated with the timbering of an earlier period) than a response to the nature of the rock conditions encountered (with the simplest, least costly solutions always preferred). We might also add that carelessness on the part of the miners could also result in what appear to be more 'primitive' techniques. Using the comparison of pottery shards from different excavations is also fraught with the danger of premature conclusions. One might even hazard the generalisation: the fewer the shards, the greater the danger. In certain cases, including Kang-hsia, one has the feeling that the excavators may not have exercised quite enough reticence here; Li Thien-yuan (*1988*), p. 41.

麻陽 on the Chhen River 辰水 in far western Hunan.[108] The area worked by the ancient miners covered some 32,000 sq. m. Very conveniently, 85 per cent of the copper, which constituted an average of 4.7 per cent of the ore,[109] was in the form of native copper granules thickly distributed in the sandstone and quartz. It has been estimated that the 130,000+ tonnes of ore excavated at this site[110] produced some four tonnes of copper[111] during the Warring States period.[112] All but one of the 14 or 15 inclined shafts were investigated, one of them (no. 12) very thoroughly.[113] Though much of the timbering of these shafts had collapsed, Ma-yang still provides important evidence of timbering techniques in use in Chinese copper mines in the second half of the –1st millennium.[114]

The southeast Anhwei mining sites

One of the richest and most extensive areas of Chinese copper deposits is southeast Anhwei south of the Yangtze River, centring on the present-day counties of Nanling 南陵, Thung-ling 銅陵, Kuei-chhih 貴池 and Chhing-yang 青陽.[115] As of 1990, the remains of some 90 copper mining and smelting sites had been identified over an area of some 2,000 square km, with about 20 appearing to date from before the –2nd century,[116] the earliest from at least the early –1st millennium (Western Chou).[117]

Miners were early drawn to this area not only because of the telltale 'iron caps' (gossan; cf. above, (*d*)(2)(ii)) that often indicated the presence of a deposit but also by geobotanical indicators.[118] Probably because the mineralogical and petrographic composition of the materials in the deposits made them more resistant to weathering

108 Barnard (1989), pp. 157–62; Hsiung Chhuan-hsin *et al.* (*1985*); Li Chhing-yuan & Li Chung-chün (*1984*). It was the opinion of the excavators (p. 122) that all the workings here began with the mining of outcrops and then slowly proceeded underground. The one thoroughly excavated shaft penetrated to a depth of 100 m, with a total length of 140 m; Li Chhing-yuan & Li Chung-chün (*1984*), p. 79.

109 Li Chhing-yuan & Li Chung-chün (*1984*), p. 80. 110 *Ibid.*, p. 79.

111 Or perhaps over six tonnes (Li Chhing-yuan & Li Chung-chün (*1984*), p. 80) or even as much as eight tonnes or more (Barnard, unpublished manuscript).

112 Chou Wei-chien *et al.* (*1990*), p. 18. Although the results of a single radiocarbon test on a wooden mallet (2730± 90 BP) would suggest a pre-Warring States dating (Hsiung Chhuan-hsin *et al.* (*1985*), pp. 113, 121), all the remaining artefactual evidence, including the style of the ceramic pieces as well as the quality of the iron in the four iron artefacts found, consistently suggests a Warring States dating. This has been accepted in most recent references to the excavation; see, e.g., Chou Wei-chien *et al.* (*1990*), p. 18; Liu Shizong *et al.* (1993), p. 58.

113 Hsiung Chhuan-hsin *et al.* (*1985*), p. 121; Li Chhing-yuan & Li Chung-chün (*1984*), p. 78.

114 The report on this excavation also raises rather gingerly the possibility (Hsiung Chhuan-hsin *et al.* (*1985*), p. 122) that thick soot buildups on roof and sidewalls may be evidence of the use of firesetting. Barnard and his collaborators, in the unpublished manuscript mentioned above (note 111), accept that firesetting was clearly used since one can see chisel marks left on the wall by the follow-up hammering and loosening of the fired rock. They also note the remains of pillars of natural rock (0.4 m thick) used as supports but supplemented by wooden timbers.

115 The following discussion is based mainly on Liu Phing-sheng (*1988*) and Chang Kuo-mao (*1988*).

116 Hua Jueming (1994), p. 2.; Chou Wei-chien *et al.* (*1990*), p. 18. Yang Li-hsin writes of some 60+ sites dating from about the –8th century (late Western Chou) to the end of the +1st millennium (Thang/Sung period); Yang Li-hsin (*1988*), p. 182. Many more sites were destroyed in the course of mining in the first half of this century; those that survived were mainly in areas such as Nan-ling that were not conducive to large-scale modern mining. Liu Phing-sheng (*1988*), p. 46.

117 Chou Wei-chien *et al.* (*1990*), p. 18.

118 Yang Li-hsin (*1988*), p. 181; Liu Phing-sheng (*1988*), p. 45. The latter report identifies the plant that indicated copper as *thung-tshao* 銅草, but the former more precisely gives its name as *thung-hsiu-tshao* 銅鏽草; both are presumably the same elshotzia (*thung-tshao hua* 銅草花) that also helped alert miners at Thung-lü shan to the presence of copper ores.

than the surrounding country rock, many of the southern Anhwei mines are found at high elevations.[119] Not all of them, however. In the area of Nan-ling and Thung-ling, there are many mines that worked deposits in lower areas of rolling hills, in cols or in level valley areas.[120]

Because the oxidation zone in this region extended to a depth of 30–60 m and contained many (though not very large) easily worked ores with high copper content, the deposits lent themselves well to exploitation by traditional techniques.[121] The presence of a layer of charcoal on the floors of the galleries as well as soot deposits in the crevices of the rocks have been taken by excavators as an indication that firesetting was widely used.[122]

Many of these sites also present a good picture of the very beginnings of shallow underground mining. At Little Broken-head Mountain (*Hsiao Pho-thou shan* 小破頭山) just south of Tha-li-mu village 塌里牧 (Nan-ling hsien), a number of square shafts measuring about 70 × 70 cm were driven vertically to depths of 5 to 8 m. At the ore level, short galleries (2–3 m) were sometimes driven, with widths and heights of only about 50 cm. Because the shafts were driven close together (about one shaft for every 14 square m), even these short galleries mostly ended up connecting one with another.[123]

Although the excavations of these southern Anhwei mines are still at an early stage and at the time of writing have not yet been fully reported, there seems no question that they constituted the major copper production centre of southeast China at least by the middle of the –1st millennium.[124] Just one of the mining and smelting operations, that of Chiang-mu-chhung 江木冲, has been calculated on the basis of an estimated 500,000 tonnes of slag to have produced more than 50,000 tonnes of copper between the –8th and –5th centuries.[125] The warfare that characterised this area during the middle centuries of the –1st milliennium may have been stimulated not only by its strategic location between the States of Wu 吳 and Chhu 楚 but also by the desire of one or another power to gain or keep control over its copper production.[126]

The Nu-la-sai 奴拉賽 *mines at Ni-lo-kho* 尼勒克, *Sinkiang*

These mines, some of whose workings may date from the Spring and Autumn period (–8th to –5th centuries) were discovered during geological surveys in 1957. There are two open-cast works, one of which measures 100 m in length and up to

119 Pittioni (1950), p. 16 notes this phenomenon in the early copper mines of Austria.

120 Yang Li-hsin (*1988*), p. 182.

121 As noted above ((*e*)(1)(i)(α)), it is at three of these sites that Chinese excavators discovered copper ingots some of whose copper apparently came from the sulphide ore chalcopyrite, suggesting the possibility that the Chinese may have been able to smelt copper from sulphide ores by about the –7th or –8th centuries.

122 Liu Phing-sheng (*1988*), pp. 48, 54.

123 Liu Phing-sheng (*1988*), pp. 47–8.

124 Yang Li-hsin (*1988*), pp. 185–6; 189.

125 Liu Phing-sheng (*1988*), p. 56. Hua Jueming (Hua Chueh-ming) estimates the total slag accumulation from these mines to be over one million tonnes; Hua Jueming (1994), p. 2. In the Thang, during the first half of the +8th century, the mines at Thung-kuan shan produced more that 150,000 tonnes of copper *per year*, Chang Kuo-mao (*1988*), p. 82, citing the *Yuan-ho Chun Hsien Chih* of Li Chi-fu.

126 Chang Kuo-mao (*1988*), p. 82.

50 m in depth. Three underground workings have also been found, with at least one surviving working platform.[127]

(ε) *Copper in China during the imperial period*

> All five of the metals found in nature are useful for the people. But gold and silver appear only in very small quantities, while iron and tin are too low in value. Only copper has proved suitable in the past as today for currency.
>
> *Sun Chheng-tse, +17th century*[128]

By the Han dynasty, the government monopoly on the minting of bronze coins consumed by far the largest part of the copper mined in China. As early as the −1st century, some 100,000 convict workers were said to be employed in the production of copper and iron[129] and, between −118 and c. +5, the government minted an average of 220 million coins per year.[130] In the following dynasties, the government found itself repeatedly trying to devise policies to close the gap between available supplies of copper and the often larger amounts needed by its mints in order to maintain a copper-based currency.[131]

It was not easy.[132] When the purchasing power of coins sank below the metallic value of the copper in the coins, people were tempted to melt down coins and use the copper for casting inferior coins or for other purposes that ran a wide gamut from daily utensils to Buddhist statues and temple bells.[133]

[127] Chou Wei-chien *et al.* (*1990*), p. 19. Too late for its results to be incorporated in any detail here, I obtained a copy of a revised draft of an article detailing the information on mining and metallurgy derived from excavations of *two* mining sites at Ni-lo-kho, Nu-la-sai and Yuan-thou-shan 园头山; see Mei Chien-chün & Li Yen-hsiang (*1995*). My thanks to Emma Bunker for providing me with this copy.

[128] *Chhun Ming Meng Yü Lu*, ch. 47, p. 8a, cited and translated in Eberstein (1974), p. 117.

[129] Chhü Thung-tsu (1972), pp. 143–4. The memorial presenting this figure is polemical; it is therefore fair to question whether the figure might be something of an exaggeration. The figure is about as high as the total number of workers in the flourishing mining industry of the Holy Roman Empire 1,500 years later; Pacey (1992), p. 105.

[130] Nishijima (1986), p. 588.

[131] Maspero & Balazs (1967), pp. 214–15; 295–6; Vogel & Theisen-Vogel (1991), p. 19. Of course, in later dynasties, and above all from the +15th century on, the Chinese currency was basically bimetallic, with silver playing an important supplementary rôle especially in large transactions (Vogel & Theisen-Vogel (1991), p. 19). Nevertheless, though the government sometimes even received tax payments in silver, never before the 19th century did it make any efforts to coin silver or control its circulation; Vogel (1989), pp. 146–7. Classical Chinese monetary thought tended to accept that the limited amounts of precious metals available made them incapable of fulfilling the essential functions of money; von Glahn (1996), Conclusion, and Sun Chheng-tse's statement leading off this section.

[132] For the period of partition, cf. Lin Shou-chin (*1955*), p. 114, fn. 1 (which, however, does a maximum of speculating based on a minimum of evidence) and Hsia Hsiang-jung *et al.* (*1980*), p. 66. For the Thang and Five Dynasties, cf. Twitchett (1963), pp. 74–83; Herbert (1976). For the Sung, cf. Yang Lien-sheng (1952), p. 38; Araki (*1938*); Hino (*1935a*:*1983*); Hsia Hsiang-jung *et al.* (*1980*), p. 98; Golas (1989), pp. 414, 417–18; 420–1. For the Yuan, cf. Schurmann (1956), pp. 131–6. For the Ming, cf. Eberstein (1974), pp. 117–130; Hsia Hsiang-jung *et al.* (*1980*), p. 152. We shall discuss the Sung efforts in more detail below (Section (*j*)) in connection with the emergence of a major hyrometallurgical copper industry in the late +11th and +12th centuries.

[133] Among items of daily use that were sometimes made of copper were woks and cooking pots, kettles, cauldrons, musical instruments, warming pans, mirrors, tobacco pipes and other smoking utensils, washbasins, ladles, scoops and shovels, vases, lamps, candlesticks, hooks, buttons, keys and locks, hinges, weights and weighing scales, ornamental fittings and inlay work, and roof tiles. It is easy to underestimate how much copper was sometimes siphoned off into these non-currency uses. For example, during the Yuan, almost 330 tonnes (500,000 *chin*) of copper were used for the statues of a single temple near Peking; Franke (1949), p. 122, cited in Eberstein (1974), p. 131, n. 9. In the Ming Yung-lo period (+1403 to +1424), a great bell cast for the Chueh-hsing Temple in Peking – the greatest bell ever cast anywhere (?) – used 37.7 tonnes of copper and 7.6 tonnes of tin; Rostoker *et al.* (1984), p. 751. For the extensive casting activities of Buddhist monasteries in the Thang, see Maspero & Balazs (1967), p. 215.

To meet their copper needs, Chinese governments regularly tried to stimulate production.[134] They had a wide variety of options available: encouraging prospecting; promoting improved technologies; lending capital for the development and operation of 'private' mines; directing officials to take over direct management of promising deposits; rewarding or punishing responsible officials according to how much copper they were able to deliver for government use.[135] The results of these efforts were mixed. Increases in production were sometimes undercut by the popularity of Chinese coins throughout much of Asia. This could lead to their export on a major scale, as happened in the +9th and +11th centuries.[136] Such exports were very difficult to control, so much so that hard-pressed and frustrated officials were sometimes led to propose drastic measures such as the cutting off of all foreign trade as the only effective way of halting the outflow of bronze and brass coins.[137] On the other hand, trade could be a means for alleviating a shortage of copper; in the first quarter of the +18th century, the government found itself relying heavily on copper imports, especially from Japan.[138]

Any efforts to estimate how much copper was being produced in China before the Thang are precluded because of a total lack of evidence on which to base even the roughest of guesses. In the Thang itself, there is some evidence to suggest that production during peak periods may have greatly surpassed 1,000 tonnes annually.[139] The 1,000 tonnes per annum figure can be compared with the estimate that all western Asia and Europe used only about 10,000 tonnes of copper in the 1,500 years between −2800 and −1300.[140] Nevertheless, the Thang state often suffered from a shortage of copper for coinage; in +780, it was estimated that minting and transport costs of new coins totalled twice their face value.[141]

In the early part of the Sung, however, vigorous encouragement on the part of the government as well as soaring private demand led to a dramatic rise in production,

[134] Insofar as increased production brought down the price of copper, this helped the government achieve another of the goals of the currency system, namely, seiniorage profits it derived from any positive difference between the value of the metal in coins (together with the cost of minting them) and the face value of the coins; von Glahn (1996), *passim*.

[135] Hino (*1935a:1983*), pp. 283–8. We examine these policies and their effect on the development of mining technology in some detail below; cf. Sections (*k*) and (*l*).

[136] Twitchett (1963), p. 79; Chhen (1965), pp. 620–2; Hino (*1935a:1983*), pp. 283–8.

[137] Hino (*1935a:1983*), p. 298.

[138] Yang Lien-sheng (1952), pp. 38–9; Vogel (1989), p. 147. See also *TKKW*, ch. 14, p. 237 (Sun & Sun (1966), p. 242). Iron could also ease the demand for copper. It was perfectly serviceable and cheaper than copper, and was commonly used for objects that, until the early modern period, would have normally been made of copper or copper alloys in Europe; Vogel & Theisen-Vogel (1991), pp. 17–18.

[139] Cf. the discussions in Vogel & Theisen-Vogel (1991), p. 9 and Hsia Hsiang-jung *et al.* (*1980*), pp. 78–9, which work out calculations of the minimum amount of copper needed yearly for coinage in the middle of the +8th century. Hsia and his colleagues also note that not all of this copper would have had to be new production. They also suggest that the far lower scattered figures found in the written records from the Thang may reflect much lower totals than what was actually achieved in periods of high production.

[140] Aitchison (1960), p. 95.

[141] Elvin (1973), p. 147. Maspero & Balazs (1967, p. 215) give an undated Thang figure of 750 cash as the cost to mint a string of 1,000 cash. For the excavation report on one Thang copper mine, see Hua Kuo-jung & Ku Chien-hsiang (*1991*).

Table 7. *Yearly copper production/quota totals in the Sung dynasty (+960 – +1279)*

Period	Yearly copper production or quota (tonnes)
+995 to +1016	1,904
+997	2,460
+1021	1,560
+1049 to +1054	3,093
+1064 to +1067	4,209
c. +1070	12,982
Before +1078	6,395
c. +1078	8,720
+1106	3,940
+1133	236
+1162	4,231
+1166	157

After Vogel & Theisen-Vogel (1991), p. 57.

to a peak of perhaps some 15,000 tonnes yearly (Table 7).[142] Such intensive exploitation led by the end of the +11th century to the exhaustion of many of China's most easily worked deposits.[143] The resulting shortage of copper was only partially alleviated by the development of an entirely new method of production, the 'wet copper process' of extracting copper from mine waters by precipitation on iron. We shall examine this development, the first large-scale industrial use of a hydrometallurgical process, in some detail in Section (*j*) below.

The Yuan government very successfully sidestepped the continuing shortage of copper by implementing a system of paper currency that enjoyed considerable success, at least in the earlier part of the dynasty. Because paper notes were also issued in small denominations, there was little need for copper coins; even after the Mongols re-established minting in +1309, only small numbers of coins were produced, mostly it would seem using copper from melted down coins and objects rather than from new mining production.[144]

As the paper currency system gradually collapsed in the early years of the Ming, the government once again experienced severe shortages of copper for coinage.[145]

[142] Hino (*1935a:1983*), pp. 288–95. This is a rate of increase over three centuries that just about equals the rate by which central European silver production surged in the almost 100 years from +1450 to +1540; Romano & Tenenti (1967), p. 313, cited in Suhling (1980), p. 145. The dramatic increase was made possible in large part by the exploitation of many substantial deposits, previously unworked on any scale, in south China; it was from this period that the south, for the first time, clearly dominates the production of copper in China; Vogel & Theisen-Vogel (1991), pp. 9–10.

[143] For example, the smelters at Te-hsing 德興 hsien in Jao-chou 饒州, which came into production in +1010, were closed in +1062. Those at Chhien-shan 鉛山 hsien, Hsin-chou 信州 were closed after 107 years of operation in +1096. The famous Tshen-shui 岑水 mine at Shao-chou 韶州 which produced in +1078 a recorded total of 7,164 tonnes of copper (about equal to the total production of Cornwall in +1800!) saw its production decline to 2,388 tonnes in +1162 and a yearly average of only 59.7 tonnes from +1165 to +1173. Kuo Cheng-i (*1983*), p. 366; Vogel & Theisen-Vogel (1991), pp. 9, 11.

[144] Schurmann (1956), pp. 131–6; Vogel & Theisen-Vogel (1991), p. 12.

[145] Eberstein (1974), p. 117. It was actually leftover Sung coins that predominated in the circulating currency of the Ming; von Glahn (1996), Chap. 3.

A long-term answer to the problem of the largely worked-out copper deposits of southeast and south central China[146] began to appear with the development of the rich copper deposits of Szechwan and Yunnan.[147] Exploitation of these deposits was already occurring on some scale by the mid-to-late +15th century. Nevertheless, realisation of their full production potential was a slow process that lasted not decades but centuries, and the few scattered figures we have on production at copper mines in the Ming (ranging only from 3 to 107 tonnes per year[148]) strongly suggest an ailing industry. Even toward the very end of the Ming, if we can judge by the +1636 *TKKW*'s several references to silver mining in Yunnan but complete silence in regard to Yunnan copper, copper mining in that province was still relatively insignificant.[149] Fortunately for the Ming government, extensive imports from Japan that reached at the end of the +17th century over 4,000 tonnes in a single year greatly supplemented the small amounts of domestic production of copper.[150] Moreover, at least by the middle of the +16th century, silver returned to prominence as an exchange medium. This did much to limit the amount of copper coinage needed, and thus the pressure on the government to increase production of copper.[151]

Copper production in Yunnan began to pick up during the Khang-hsi 康熙 period (+1662 to +1722) of the following Chhing dynasty and acquired major significance during the following Yung-cheng 雍正 reign (+1723 to +1735), reaching a total of over 6,000 tonnes in +1737 (Table 8). When production at the Yunnan mines peaked in the late +18th century, that province alone probably produced almost as much copper as all of China in the +11th century, the high-point of copper production before the Chhing.[152] Moreover, as the Vogels point out, the Yunnan record of high levels of production over almost a century is unmatched in Chinese history.[153] For the first time, a Chinese dynasty was able to maintain a steady supply of copper for its mints without encountering recurring shortages.[154]

Much of this production was made possible by the presence in Yunnan of large deposits of the sulphide ore chalcosite, which is theoretically more than twice as rich as a source of copper as the more common sulphide, chalcopyrite (see Table 6). It was at this time that chalcosite became the major copper ore mined in China.[155]

[146] 'Worked-out', of course, only in terms of the capacities of the existing technology.

[147] It is interesting that, of the only five copper production sites given in a list in the monograph on fiscal administration in the *Yuan Shih*, two are in Yunnan: *ta-li* 大理 and Chheng-chiang 澂江; *Yuan Shih*, ch. 94, p. 25412a; Schurmann (1956), p. 153; Nakajima (*1940*), p. 415.

[148] Vogel & Theisen-Vogel (1991), p. 13.

[149] Eberstein (1974), p. 123; Sun (1964), p. 55; Wu Chheng-ming & Hsu Ti-hsin (*1987*), pp. 625–6; Vogel (1989), p. 148. But by the very end of the Ming (+1643), the loss to rebels of the southwestern copper-producing areas encouraged some officials to argue for substituting paper money for coins as China's primary circulating medium; von Glahn (1996), chap. 6.

[150] Vogel & Theisen-Vogel (1991), pp. 13 and 4, fn. 4.

[151] Eberstein (1974), pp. 122–3. Nevertheless, in times of copper shortages, which drove up the price of copper relative to silver, it could still happen that copper cash were demanded even in larger transactions such as the sale of houses; Vogel (1989), p. 147.

[152] Vogel & Theisen-Vogel (1991), p. 15; Hsia Hsiang-jung *et al.* (*1980*), p. 162; Sun (1964), p. 56. In the +18th century, the Chhing government minted as much as three billion cash yearly; Lee (1987), p. 234.

[153] Vogel & Theisen-Vogel (1991), p. 15. [154] Vogel (1987a), V.1.

[155] Hsia Hsiang-jung *et al.* (*1980*), p. 242, 249–50; Sun (1964), p. 56.

Table 8. *Copper production in Yunnan during the Chhing dynasty (+1644–1911)*

Period		Total production (tonnes)[a]
+1716		239
+1737		6,000+
+1764		c. 9,000
1800		c. 6,000
1862 and after		300–600
[a] By way of comparison:		
1800	Total 'world production'	10,000
1920s–1930s	Total Yunnan production	800–2,000
1952	Total Chinese production	10,000
1975	Total Chinese production	200,000

After figures in Vogel & Theisen-Vogel (1991), p. 14 and Vogel (1987a), I, 2; Lee (1987), pp. 215–17. For scattered figures on copper production in other provinces during the Chhing, see Vogel (1987a), IV, 2, b.

Yunnan also had highly prized cuprite and native copper deposits, but their resistant country rock (barite, porphyrite), together with the infrequent use of explosives in Yunnan mining, often meant that they were unwinnable in the Chhing.[156]

(ii) *Tin*

(α) *Geological occurrence*

Tin almost never appears in nature as a native (uncombined) metal.[157] The major ore of tin is the dioxide, cassiterite, often called in English 'tinstone', 'wood tin', or 'wood metal'. It occurs in veins (usually referred to as 'lodes') or in alluvial or eluvial deposits (in the latter of which it is commonly referred to as 'shode tin'). Unlike malachite and azurite, the common carbonate copper ores, or galena, the lead sulphide ore, nothing in the appearance of vein forms of cassiterite makes it immediately recognisable as a special kind of rock; it lacks distinctive colouring or a metallic lustre.[158] On the other hand, cassiterite is often associated with gold in placers, where it appears in the form of easily noticeable heavy black sand or nodules. In this context, it could hardly have been ignored by early gold panners though in early times they would have discarded such sands or nodules as having no use.[159]

The tin content of cassiterite is very high, up to 80 per cent. That, together with the fact that it is an oxide with a low melting point of 232 °C, makes cassiterite an

[156] Read (1912), p. 44, citing LeClère (1901).

[157] Sorrell & Sandström (1973), p. 74. Aitchison (1960), p. 78 says 'never', but Mantell notes the occasional presence of grains of metallic tin as a subordinate admixture in gold mines; Mantell (1949), p. 70. In any case, such occurrences would be of no economic significance.

[158] Hsia Hsiang-jung *et al.* (*1980*), p. 200.

[159] Tylecote (1992), p. 18. Cassiterite is actually white when pure but usually appears earthy brown to black because of iron and other impurities.

easy ore to smelt, even accidentally.[160] Hence, its rôle as a tin ore was probably discovered quite early.[161]

Despite the ease of smelting, however, much of the cassiterite in China has a very high iron content, which adds significantly to the difficulty of producing a very pure tin.[162] Indeed, traditional smelting practices in China were never able to produce a tin of sufficient purity to meet the standards of the modern international market.

All the economically significant primary deposits of tin in China as everywhere else derive from infillings of cassiterite in granite or granitic rocks (quartz, pegmatite, aplite, greisen, etc.).[163] In China, the major tin deposits are confined to granite and limestone contact metamorphic zones in the mountainous region of the Nan Ling 南嶺 range and in the hills to the north and west of it. This includes deposits in the provinces of Yunnan, Hunan, Kiangsi, Kwangtung and Kwangsi (Map 7).[164]

Because cassiterite has a high specific gravity, is extremely impervious to weathering, and endures unaltered through geological ages,[165] it can often be found in placer deposits.[166] It is important to distinguish between placer deposits of tin in existing rivers and streams and 'stream tin' in the strict sense. Stream tin deposits are former placer deposits that have since been covered with varying thicknesses of overburden (worthless surface material) and cannot be exploited without excavating. Thus, the *shui hsi* 水錫 deposits described in Sung Ying-hsing's *TKKW* are placer deposits and not, as the Suns translate it, stream tin.[167]

Especially for a mineral with a non-metallic lustre, cassiterite is very heavy, with a specific gravity of 7, thus higher than that of most other minerals with which it tends to be associated. Grains, pebbles or lumps of cassiterite can quite easily be mined from placer deposits by washing or 'streaming'.

Sung Ying-hsing's main categorisation of tin deposits is based exclusively on where the deposits are found, not on whether they are primary (vein or lode) deposits or secondary (placer) deposits. Thus he speaks of mountain tin (*shan hsi* 山錫), which can be either lode or eluvial, and "water tin" (*shui hsi*).[168]

160 When cassiterite is associated with pyrite, chalcopyrite, bornite etc. in complex sulphide ores, the smelting is much more difficult; Mantell (1949), p. 99. These ores are much less accessible, however, and were never worked in China on any significant scale.

161 Forbes (1954), pp. 589–91; Wheeler & Maddin (1980), p. 105; Hodges (1970), p. 79; Rickard (1932), p. 330. Mantell suggests (1949, p. 1) that the connection could have been made between these sands and the metal tin when the sands were used to bank a campfire, leading to the appearance of an unexpected bright and shiny metal.

162 Chhen Ping-fan (*1954*), p. 185.

163 Mantell (1949), pp. 66–7; Weng Wen-hao (*1919*), p. 194. Cassiterite is noticeably absent in traditional Chinese writings on metals and metallurgy; Hsia Hsiang-jung *et al.* (*1980*), p. 275.

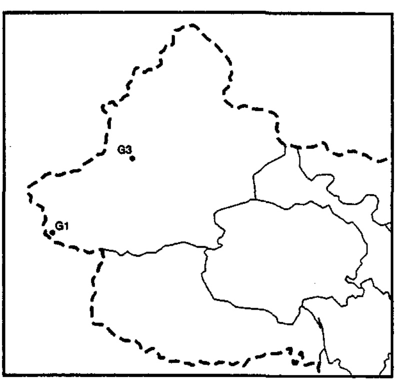
164 Weng Wen-hao (*1919*), p. 191; Wei Chou-yuan (1946), p. 442. Prior to the discovery of the massive deposits at Ko-chiu in Yunnan, Kwangsi was China's major producer of tin; cf. *TKKW* 14, p. 240 (Sun & Sun (1966), p. 251), which gives the major tin producing sites in the early +17th century. Two Yunnan sites considerably to the northwest of Ko-chiu (Ta-li 大理 and Chhu-hsiung 楚雄) are mentioned both for their tin production and their inaccessibility, but the Ko-chiu area is not. Kiangsi has become a major tin producer only in this century.

165 Jones (1955), p. 192.

166 China's richest placer deposits occur in Kiangsi where placer beds are commonly 2–3 m thick and yield anywhere from 300 to 2,500 grams of tin per cubic metre.

167 Cf. Penhallurick (1986), pp. 154–5; Sun & Sun (1966), p. 251.

168 The Suns miss the dual sense of 'mountain tin' when they explain it as 'tin stone deposits on hillsides', which suggests only eluvial deposits; Sun & Sun (1966), p. 251. Compare also Hsia Hsiang-jung *et al.* (*1980*), p. 275 which, wrongly I think, says that Sung is referring only to placer tin (*sha hsi*).



Map 7. Pre-20th century tin/lead mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A	Liaoning	H	Kiangsu	P	Hunan
B	Hopeh	J	Anhwei	Q	Szechwan
C	Shantung	K	Honan	R	Kweichow
D	Shansi	L	Chekiang	S	Kwangtung
E	Shensi	M	Fukien	T	Kwangsi
F	Kansu	N	Kiangsi	U	Yunnan
G	Sinkiang	O	Hupeh	V	Kirin

Caption to Map 7. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 7

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
B5	Wu-an	武安					X			
B6	Luan-chou	灤州	Luan-hsien	灤縣					X	
B7	Yen-chhing	延慶								X
C6	Chhing-chou	青州	Teng-lai	登萊	X				X	
C1	Lai-wu	萊蕪					X			
C7	Chiao-chou	膠州							X	
C8	Chi-nan	濟南							X	
C9	Lai-chou	萊州							X	
C4	Lin-chhü	臨朐								X
C5	Chü-chou	莒州								X
C10	I-tu	益都								X
D19	Huai-shan	槐山	Wen-hsi	聞喜	X					
D15	Yang-chheng	陽城					X		X	
D20	Chiao-chheng	交城							X	X
D9	Phing-lu	平陸							X	
D9	Phing-lu Chi shan	平陸箕山								X
E17	Mien-hsien	勉縣					X			
E18	Feng-li	豐利					X			
E19	Hsi-hsien	西縣					X			
E8	Shang-chou	商州						X		
E20	Hsing-yuan fu	興元府	Han-chung	漢中				X		
E9	Lung-chou	隴州						X		
E21	Feng-hsiang fu	鳳翔府						X		
E22	Thung-chou fu	同州府	Ta-li hsien	大荔縣						X
E3	Hua-yin	華陰								X
E23	Hsun-yang	洵陽								X
G1	Nan-erh	難兒				X				
G3	Kuei-tzu	龜茲				X				
H3	Chü-jung	句容					X			
J1	Hsuan-chou	宣州	Hsuan-chheng	宣城			X			
J14	Chi-hsi	績溪					X			
J15	Chhiu-phu	秋浦					X			
J13	Thung-ling	銅陵							X	
K8	Le-an	樂安	Kuang-shan	光山			X			
K9	Chhang-shui	長水	Lu-shih	盧氏			X			
K10	I-yang	伊陽					X			
K5	Kuo-chou	虢州						X		

Key to Map 7 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
K10	I-yang hsien	伊陽縣	Hsi-ching	西京				X		
K11	Kung-chheng hsien	共城縣	Wei-chou	衛州				X		
K12	Teng-chou	鄧州	Chi-hsien	汲縣				X		
K13	Wu-an	武安					X		X	
K14	Chhi-hsien	淇縣							X	
K3	Lu pao shan	露寶山	Sung-hsien	嵩縣					X	
K15	Yung-ning	永寧							X	
K3	Sung-hsien	嵩縣							X	
K16	Lin-ju	臨汝							X	
K10	Shai-tzu to shan	篩子朶山	I-yang	伊陽					X	
L4	An-chi	安吉					X		X	
L15	Hui-chi	會稽	Shao-hsing	紹興			X			
L15	Yueh-chou	越州	Shao-hsing	紹興				X		
L16	Chhü-chou	衢州						X		
L11	Chhu-chou	處州						X	X	
L17	Thai-chou	台州	Lin-hai	臨海					X	
L18	Lung-chhüan	龍泉							X	X
M15	Chien-chou	建州						X		
M9	Thing-chou	汀州						X		
M10	Chang-chou	漳州						X		
M11	Nan-chien chou	南劍州						X		
M12	Shao-wu chün	邵武軍						X		
M16	Yen-phing	延平	Nan-phing	南平					X	
M12	Shao-wu	邵武							X	
M17	Chien-ning	建寧							X	
M5	Chhang-thing	長汀							X	
N15	Nan-khang	南康					X			
N9	Ta-yü	大庾					X			
N16	An-Yuan	安遠					X			
N8	Shang-jao	上饒					X		X	
N17	Nan-khang hsien	南康縣						X		
N10	Chhien-chou	虔州						X		
N9	Nan-an chün	南安軍	Ta-yü	大庾				X		
N8	Hsin-chou	信州						X		
N18	Chhien-shan	鉛山							X	
N5	Le-phing	樂平							X	
O16	Yun-hsi	鄖西				X				
O17	Ku chheng hsien	谷城縣	Hsiang-chou	襄州				X		
O18	Hsia-chou	峽州	I-chhang	宜昌				X		X
O19	Thung-chheng	通城							X	
O20	Yun-hsien	鄖縣							X	X
O9	Chu-shan	竹山								X
O21	Fang-hsien	房縣								X
O10	Ho-feng	鶴峰								X
O22	Hsing-kuo	興國								X
O23	Ma-chheng	麻城								X
O6	Ching-shan	京山								X
O12	En-shih	恩施								X
O15	Chien-shih	建始								X
O24	Chhi-chhun	蘄春								X
O25	Tang-yang	當陽								X
O26	Ku-chheng	穀城								X
O27	Hsing-shan	興山								X

Key to Map 7 (*cont.*).

	Sites		Further identification		P1	P2	P3	P4	P5	P6
O28	Yang-hsin	陽新								X
O13	Hsien-feng	咸豐								X
O29	Hsien-ning	咸寧								X
P1	Chhang-sha	長沙				X	X			
P2	Phing-yang	平陽					X			
P3	Kao-thing	高亭					X			
P14	Chiang-hua	江華					X		X	
P15	I-chang	義章					X			
P16	Feng-chheng	馮乘					X			
P17	Tao-chou	道州						X		
P7	Chhen-chou	郴州						X		X
P8	Heng-chou	衡州						X	X	
P18	Kui-yang chien	桂陽監						X		
P5	Than-chou	潭州							X	
P19	Yung-chou	永州	Ling-ling	零陵					X	
P4	I-chang	宜章							X	X
P20	Lei-yang	耒陽							X	X
P10	Chhang-ning	常寧							X	
P21	Kui-yang chou	桂陽州							X	
P22	Li-ling	醴陵							X	
P2	Kui-yang	桂陽								X
P23	Liu-yang	瀏陽								X
Q26	Chu-thi	朱提	I-pao	宜賓		X				
Q25	Feng-chieh	奉節					X			
Q27	Chiang-yu	江油					X			
Q28	Lung-an fu	龍安府	Phing-wu	平武					X	X
Q17	Chia-chou	嘉州	Le-shan	樂山					X	
Q29	Li-chou	利州	Kuang-yuan	廣元					X	
Q30	Chien-chou	劍州	Chien-ko	劍閣					X	
Q31	Ya-chou	雅州							X	
Q32	Chhang-ning	長寧								X
Q33	Shih-chu	石柱								X
Q34	Lung thou shan chhang	龍頭山廠	Lei-po	雷波						X
Q23	Mien-ning	冕寧								X
Q3	Ying-ching	滎經								X
R3	Su-chou fu	思州府	Tshen-kung	岑鞏					X	
R4	Thung-jen	銅仁							X	
R5	Pi-chieh	畢節								X
R6	Shui-chheng	水城								X
R7	Tu-yun	都勻								X
R8	Chhing-phing	清平								X
S15	Hua-meng	化蒙	Kuang-ning	廣寧			X			
S1	Yang-chhun	陽春					X			
S16	I-ning	義寧						X		
S17	Chhao-chou	潮州						X		
S18	Hsun-chou	循州	Lung-chhuan	龍川				X		
S19	Lien-chou	連州						X		X
S3	Ying-chou	英州						X		
S1	Chhun-chou	春州	Yang-chhun	陽春				X	X	X
S4	Shao-chou	韶州						X	X	
S5	Kuang-chou	廣州						X		
S20	Hui-chou	惠州						X		
S21	Khang-chou	康州	Te-chhing	德慶				X		

Key to Map 7 (*cont.*).

	Sites		Further identification		P1	P2	P3	P4	P5	P6
S22	Nan-en chou	南恩州						X		
S23	Kao-chou	高州						X		
S24	Chhao-chou mei chou	潮州梅州						X		
S7	Kuei-yang	桂陽							X	
S25	Hsin-hui	新會							X	
S26	Hai-yang	海陽							X	
S27	Chheng-hsiang	程鄉							X	
S28	Te-chhing chou	德慶州							X	
S29	Lung-shui	瀧水	Lo-ting	羅定					X	
S30	Fan-yü	番禺							X	
S31	Weng-yuan	翁源							X	
S32	Le-chhang	樂昌							X	
S33	Jen-hua	仁化							X	
S34	Chhang-le	長樂								X
S35	Kao-ming	高明	Ming-chheng	明城						X
S36	Feng-shun	豐順								X
S37	Chia-ying chou	嘉應州	Mei-hsien	梅縣						X
S38	Yang-chiang	陽江								X
T9	Feng-chheng	馮乘	Fu-chhuan	富川			X			
T10	To-chin	鐸津	Theng-hsien	藤縣			X		X	
T11	Yü-lin	鬱(林)					X			
T12	Than-chin	鐔津					X			
T13	Ho-chou	賀州						X		
T14	Theng-chou	藤州						X		
T15	Jung-chou	融州						X		
T1	Lin-he	臨賀	Ho-hsien	賀縣			X			X
T5	Nan-tan	南丹							X	X
T16	Ho-chhih	河池							X	X
T17	Fu-chou	富州							X	
T18	Shang-lin	上林							X	
T19	Kuei-hsien	貴縣							X	
T20	Fu-chhuan	富川					X			X
T4	Kung-chheng	恭城								X
T21	Hsuan-hua	宣化								X
T22	I-ning	義寧								X
T23	Jung-hsien	融縣								X
U31	Lü-kao	律高	Lu-liang	陸良		X				
U32	Pen-ku	賁古	Chien-shui	建水		X				X
U3	Ai-lao	哀牢				X				
U33	Tien	滇	Khun-ming	昆明		X				
U4	Ta-li	大理							X	X
U34	Chhu-hsiung	楚雄							X	X
U35	Lo-tzhu	羅次							X	
U36	Hsin-hsing	新興	Yü-hsi	玉溪					X	
U37	Ko-chiu	個舊								X
U23	Meng-tzu	蒙自								X
U5	Tung-chhuan	東川								X
U38	Hsun-tien	尋甸								X
U8	Chen-hsiung	鎮雄								X
U39	Thung-hai	通海								X
U40	Li-chiang	麗江								X
U41	Lo-phing	羅平								X
U42	Phing-i	平彝								X

(β) *Tin and the early bronzes*

Tin by itself is not a very useful metal: objects made of tin are prone to cracks during working and also to breakage afterward because of tin's directional solidification.[169] On the other hand, tinning (dipping an object in molten tin or wiping it with molten tin) was useful for imparting a silvery colour to bronzes, and the technique flourished in China as early as the middle of the –1st millennium.[170] By far the most important early use of tin in China was in combination with copper to produce bronze. The new alloy, especially when it contained about 10 per cent tin, was vastly superior to copper in hardness and tensile strength (both especially desirable in the production of swords, dagger-axes (*ko* 戈), spear-heads (*mao* 矛) and other weapons) and in fluidity during-casting (thus helping make possible the complex decoration of Shang bronzes).[171]

There are two ways that bronze could have been produced accidentally in early times.[172] Under the right conditions (especially a sufficiently high source of heat), bronze could have resulted from the melting of native copper that happened to contain tin as an impurity, thus forming an unintentional alloy. In this case, however, the percentage of tin would ordinarily be so low that the alloy should be considered 'bronze' only in the most narrowly technical sense of the term.[173] Most of the discussion of this subject, therefore, has focused on the accidental alloying of *ores* containing tin and copper which could offer much higher percentages of tin. Desch long ago argued that these complex ores are of such a compostion that they could not yield bronze when reduced.[174] Noel Barnard, however, adduces considerable evidence to conclude that 'the unintentional alloying of tin–copper bronzes . . . may well be considered valid as a working hypothesis in the Chinese scene.'[175] Given the present state of our knowledge, we can only assume that when numbers of bronzes with significant (and perhaps consistent) tin content[176] begin to appear, they testify to the intentional combination of tin, either as a metal or in an ore, with copper to produce bronze.[177]

We have already discussed above[178] the likelihood that the copper for early bronzemaking in north China came mainly from copper deposits in the north. The same seems to be true for tin, though here too we are lacking conclusive evidence

[169] Wheeler & Maddin (1980), p. 105. A few tin objects (e.g., dagger-axe *ko* 戈 blades) from the late Shang have been found (Hsia Hsiang-jung *et al.* (*1980*), p. 20) but they were almost certainly meant only to serve as burial objects.

[170] Bunker (1994), pp. 74–5. In the Pa-Shu culture of the Warring States period, an alternative technique, that of mercury amalgam tinning, was also used; *Ibid.*

[171] Desch (1927), p. 361; Forbes (1954), p. 590; Aitchison (1960), p. 82.

[172] The best discussion to date of this subject as it relates to the emergence of bronze both in early cultures generally and in China in particular is Barnard (1989), pp. 186–92, which introduces much of the important relevant literature in English.

[173] Patterson (1971), p. 310 notes that native copper is typically 99.9% pure. [174] Aitchison (1960), p. 62.

[175] Barnard (1989), p. 191. Only hard archaeological evidence, not yet available, might be able to prove this hypothesis. Absence of such evidence, however, can never disprove it.

[176] Barnard & Satō (1975), pp. 16ff.

[177] The same is true for the arsenic in arsenic bronzes of the Aegean; see Vol. 5, pt. 2, p. 224.

[178] Section (*e*)(1)(i)(γ).

for the exploitation of northern tin deposits during the Shang, not to speak of linking the tin of specific pieces to particular deposits. Nevertheless, the fact that the Shang Chinese, in contrast to bronzemakers to the west, rarely chose to incorporate arsenic (which can substitute for tin in bronze) in their bronzes suggests rather easy availability of tin at this time, thus enabling them to cast their bronzes without running the risk of poisoning by arsenic.[179]

Not all scholars, however, accept the conclusion that tin was reasonably available in north China deposits during the Shang. In their history of mining in China, Hsia Hsiang-jung, Li Chung-chün and Wang Ken-yuan, drawing on some very old data compiled by the Japanese scholar Dōno Tsurumatsu 道野鶴松 before World War II, argue that the chemical compositions of the 34 late Shang dagger-axes recovered from the wastes of Yin show that the makers of bronze weapons at this time knew the copper/tin ratio for producing hard bronze suitable for weapons.[180] Nevertheless, 19 of the pieces contain only trace or negligible amounts of tin. To account for the poor metal used in these weapons (as well as the complete lack of significant amounts of tin in fifteen spear-heads also studied by Dōno), the authors posit a shortage of tin for weapons in north China caused by the need to import from the south all tin used in north China bronzecasting, as well as the practice of using the best tin bronze in ritual objects and only what was left over in weapons. Many questions can be raised about this interpretation. Ultimately, however, it remains seriously open to question simply because it attempts to establish a very important point (the complete absence of tin mining in the central plain area) on the basis of a pitifully narrow body of evidence. Moreover, as is clear from Map 4, the authors are completely mistaken in their belief that there was no tin available in or surrounding the area of the Shang bronzemaking installations.[181]

The question of the source of tin used in Shang bronzemaking is further complicated by the possibility that tin may have been significantly more abundant in the late Shang since it appears to have increasingly replaced lead in late Shang bronzes.[182] Here too, however, caution is in order. An alternative to the increasing supply theory is provided by An Chih-min, who detects a growing specialisation of alloys in the course of the Shang, with tin bronzes predominating in ritual vessels *and weapons* while ordinary tools and burial objects tend to use more lead in place of tin.

Whatever the availability of tin in north China during the Shang, it was much more abundant in south China, both in vein deposits and as residual or alluvial

[179] Vol. 5, pt. 2, pp. 223–4; Barnard & Satō (1975), p. 23.

[180] Though this was indeed probably known, the authors are not explicit on how they derive the fact of that knowledge from these 34 dagger axes; cf. Hsia Hsiang-jung *et al.* (*1980*), pp. 204–5; 207. Presumably, it is because, of the 15 pieces that contain significant tin content, the proportion of tin ranges from about 7 to 15% in 14 of those pieces, suggesting that they were aiming for something like 10% tin content, which would have resulted in a very tough metal.

[181] Of course, given the frequent confusion of lead and tin deposits, it is possible that some of the tin deposits mentioned in the written sources were actually lead deposits. But that is not likely to be true for all or even a majority of such identifications. Moreover, Wen Kuang has produced a map that gives a further 17 north China tin deposits known in traditional times that do not appear in Shih Chang-ju's list; Wen Kuang (*1980*), p. 427.

[182] Murray (1983), p. 67.

deposits. China is one of only a half-a-dozen or so places in the world with substantial tin deposits.[183] As mentioned above, the main Chinese deposits at present are concentrated in the five provinces of Yunnan, Kwangsi, Hunan, Kiangsi and Kwangtung, with those of Yunnan and Kwangsi by far the most important.[184] Moveover, there were many cases (e.g. Ta-yü 大余 hsien in Kiangsi and the Kuei-yang 桂陽/Chhen-hsien 郴縣 area of Hunan) where copper and tin could be found associated in relatively easy-to-work deposits.[185] Hsia Hsiang-jung, Li Chung-chün and Wang Ken-yuan, in an argument that hearkens back to earlier interpretations proposed by, among others, Kuo Mo-jo and Umehara Sueji,[186] suggest two very early traditions of bronzemaking in China: a northern tradition that produced copper/lead bronzes (i.e., bronzes where lead content was relatively high compared to tin) and a southern tradition that produced mainly copper/tin bronzes.[187] For the present, this remains a hypothesis that needs testing as more data on the metallic composition and provenance of greater numbers of early bronzes becomes available.

(γ) *Other uses of tin*

By the Shang dynasty, the Chinese were also using tin for tin plating or 'tinning'.[188] Out of this technique may have come the tin foil industry which in later periods used considerable amounts of tin beaten into leaves to produce the 'spirit money' that was burned at Chinese funerals as offerings for the deceased.[189] Tin was also alloyed with lead to produce a pewter that was used in many objects and ornaments of daily and religious use. Thin plates of lead and tin were widely used to line tea chests in late imperial times[190] while a mercury–tin alloy was used to coat mirrors. At some point, still unknown but probably Han or later,[191] the usefulness of a tin–lead alloy as a solder was discovered. Finally, tin could also serve with acids as a mordant and to give brilliancy to certain dyes.[192]

(δ) *Tin mining at Ko-chiu in late imperial times*

The tin mines of Ko-chiu 箇舊, by far the most important tin mining centre of the Chhing period, offer an excellent example of a major mining site of late imperial times. We have here an example of a very large-scale mining operation (with up to some 100,000 people connected directly or indirectly with mining and smelting) that even throughout the first half of this century continued, despite the availability of seemingly more advanced technology, to rely overwhelmingly on techniques

[183] Tylecote (1992), p. 18. [184] Wang Hua-lung (*1960*), p. 114. [185] Hsia Hsiang-jung *et al.* (*1980*), p. 207.
[186] Amano (*1953*), pp. 231–2. [187] Hsia Hsiang-jung *et al.* (*1980*), pp. 198–210.
[188] Anon. (*1978b*), p. 12, fn. 1; Hsia Hsiang-jung *et al.* (*1980*), p. 20; Vol. 5, pt. 2, p. 233. For an illustration of a Warring States pottery vessel coated with tin foil, cf. Cheng Te-khun (1963), pl. 10.b.
[189] Interestingly, in the characteristics of ductility and malleability, tin is the opposite of silver (cf. above, Section (*e*)(1)(v): it is not very ductile (Thien Chhang-hu (*1987*), p. 283) but is quite malleable.
[190] Gillan (1962), p. 296. [191] Barnard & Satō (1975), p. 73. [192] Couling (1917), p. 371.

hundreds if not thousands of years old.[193] Because of relatively good data on this complex, we are able to examine in some detail various reasons for this lag, many of which must be sought in other than technological factors. I will give here a general survey of mining operations at Ko-chiu but reserve for the relevant sections below the closer examination of the techniques used as well as a discussion of why traditional techniques exhibited such great staying power at Ko-chiu.

The Chinese knew of the existence of tin deposits and mines in the Ko-chiu region at least by the −2nd century, in the reign of Emperor Wu 武 of the Han dynasty.[194] Unfortunately, the texts that tell us there was tin mining in this area provide no details on the methods used. They were undoubtedly very small-scale. For the period afterwards, down to the Yuan and Ming, there seems to be no surviving information whatsoever on any mining activity at Ko-chiu.

Later traditions date the beginning (actually a revival?) of mining at Ko-chiu to the Yuan or Ming dynasties.[195] However, there seem to be no surviving records of specific mining activity before the Chhing. The traditions also suggest, almost certainly correctly, that the Yuan and Ming mining focused on argentiferous galena deposits from which the miners could extract lead and, especially, silver.[196] As the galena gave out at depth, it was often replaced by cassiterite, thus encouraging tin mining.[197] This geological pattern helps to account for the very deep shafts that were common at the tin mines of Ko-chiu.

In the late +15th century, a prefecture was established at Meng-tzu 蒙自, some 50 km to the east of Ko-chiu,[198] and an almost contemporary Yunnan gazetteer tells us specifically that Ko-chiu village (*tshun* 村) was producing tin and lead at this time.[199]

The Chhing government established a tax on silver production at Ko-chiu in +1677,[200] and not long afterward also implemented a tax on tin production (*hsi-shui* 錫稅) as well as a further tax paid by merchants who exported tin from Yunnan.[201] Extrapolation from the figures given in this memorial suggests that merchants were exporting from Ko-chiu at this time over one and a quarter million *chin* or some 850

193 Various authors generally agree that 90% of Ko-chiu's tin production as late as the 1930s was accomplished with traditional techniques that showed virtually no influence from more modern methods. Tin technology has everywhere tended to remain rather crude right up until quite recently. Herbert and Lou Henry Hoover, in their indispensable annotated translation of Agricola's *De Re Metallica*, note the tendency of tin production to lag technologically behind production of other metals. 'In general, since Agricola's time tin has not seen the mechanical and metallurgical development of the other metals. The comparatively small quantities to be dealt with; the necessity of maintaining a strong reducing atmosphere, and consequently a mild cold blast; and the comparatively low temperature demanded, gave little impetus to other than crude appliances until very modern times.' Hoover & Hoover (1912), p. 413, fn. While the Hoovers' focus is on the lag in smelting technology, we shall see that the same phenomenon reveals itself also in mining and ore dressing.

194 For the relevant texts, cf. Su Ju-chiang (*1942*), pp. 17–18; Chhen Lü-fan (*1980*), p. 5.

195 Su Ju-chiang (*1942*), p. 18; Wang Hua-lung (*1960*), p. 114. 196 Rocher (1879–1880), Vol. 2, p. 231.

197 Weng Wen-hao (*1919*), p. 192; Huang Chu-hsun (*1930*), p. 54.

198 The year was 1477; Chhen Lü-fan & Tsou Chhi-yü (*1979*), p. 2; Su Ju-chiang (*1942*), p. 12.

199 Chhen Lü-fan *et al.* (*1979*), p. 1. 200 Wu Chhi-chün (*1845*), ch. 2, p. 16b.

201 Anon. (*1983*), Vol. 2, p. 601. The tradition surrounding the beginnings of tin mining at Ko-chiu places the first discoveries of cassiterite at about this time; cf. below, Section (*i*)(2).

tonnes of tin yearly.[202] Just before the end of the dynasty, in 1885, Ko-chiu became a subprefecture (*thing* 廳) whose officials were concerned almost exclusively with the general supervision of mining, especially tin mining, as well as the collecting of mining taxes.[203]

The Ko-chiu tin-mining district is situated in southeastern Yunnan some sixty-five km from the nearest point on the border with Vietnam. The mines are all found at a distance of 5 to 12 km from Ko-chiu in a range of mountains running roughly north–south and separating the town of Ko-chiu to the west from the Meng-tzu 蒙自 plain to the east. The area in which workable deposits have been found stretches only about 35 km north–south and some 20 km east–west, with most of the mining up to the beginning of this century concentrated in four major centres.[204] The mines are 2.5 to 2.8 km above sea level.[205] The area enjoys a climate ranging from temperate at the higher elevations to sub-tropical in the valleys. Very important for the mining of tin, it receives considerable rainfall; up to 60 cm or more per year. The rain is concentrated, however, in a rainy season which lasts from about May to September, with occasional showers until around February. Total rainfall averages 225 cm annnually.[206] This rainy season was the key determinant of a distinct yearly mining cycle at Ko-chiu.

It was also availability of water as well as the nature of the deposits that, above all, influenced *how* tin mining was carried on at Ko-chiu. The Ko-chiu tin deposits, as is typical for south China, are found in a contact metamorphic zone where the limestone country rock has been intruded along a generally north–south course by the tin-bearing granite lying beneath it. The tin content of the complex sulphides that made up the primary deposits would have been too low to permit them to be mined economically.[207] But the miners at Ko-chiu were able to rely almost exclusively on rich secondary deposits in which the tin had been concentrated by residual (chemical weathering) and/or alluvial (transport by water) processes[208] under 'unusually favorable conditions for oxidation'.[209] The cassiterite is typically found in solution passageways in the limestone; these had been dissolved by ancient streams and then silted up with placer tin.[210] The ore bodies thus tend to be oblong and to follow the

[202] By +1735, this figure had increased to over 1,000 tonnes yearly; Anon. (*1983*), Vol. 2, p. 602.

[203] Chhen Lü-fan & Tsou Chhi-yü (*1979*), p. 2; Chu Hsi-jen *et al.* (*1940*), p. 62.

[204] Anon. (1926), p. 154. Draper (1931, p. 181) would make the area even smaller, some fifteen by nine km.

[205] Draper (1931), p. 178.

[206] Chu Hsi-jen *et al.* (*1940*), p. 62; Su Ju-chiang (*1942*), p. 12; Collins (1909–1910), p. 189; Draper (1931), pp. 179–80.

[207] Huang Chu-hsun (*1930*), p. 54; Chhen Ping-fan (*1954*), p. 186.

[208] This classification accords with our discussion above, Section (*d*)(2). Some authors would classify a portion of the Chinese tin deposits as 'primary replacement and fissure-filling deposits.' Cf. Wei Chou-yuan (1946), p. 442.

[209] Draper (1931, p. 183) lists these conditions: 'the situation of the deposits some 3,000 ft. or more above an adjoining plane of drainage on steep mountains in faulted and fissured limestones, with alternating seasons of dry weather and heavy rainfall . . .'. The result was that 'any residual sulfides are extremely rare'.

[210] Cressey (1955), p. 144. Fissures and caves in the limestone are common and sometimes surprisingly large. By assisting both drainage and ventilation, they have greatly contributed to the ability of miners to work at great depths. Draper (1931), p. 181.

bedding planes of the limestone.[211] Most of the deposits that were originally surface deposits have since been covered with varying thicknesses of overburden so that tin mining at Ko-chiu usually requires at least some excavation to arrive at the cassiterite. Because most of the Ko-chiu placer deposits have resulted from a kind of vertical concentration whereby the solution of limestone *in situ* has caused the cassiterite to settle at the bottom of sinks,[212] there is no significant panning of tin along stream banks as has been practised extensively by Chinese tin miners in Hunan, Kwangsi and Kiangsi.

Reports on the quality of the ores at Ko-chiu are far from consistent. On the basis of extensive evidence, however, Draper was able to conclude that the average grade for all crude ore, i.e., ore from lodes, was 'well above 5 per cent contained tin'.[213] Shih Kuo-heng, writing in 1947 but probably basing himself on earlier information, gives a figure of 'about 8 per cent', which is near the maximum found in tin lodes.[214] Wei Chou-yuan, writing about the same time, gives an average grade of 2.4 to 5 per cent[215] while still another estimate, reflecting perhaps the increasing working out of the richer deposits, puts the average tin content of the ore at 3.36 per cent.[216]

In any case, the deposits were so extensive that, even well into this century and therefore after some 200 years of tin mining in this area, there were few abandoned workings to be seen.[217] Only since World War II has the tin mining industry at Ko-chiu gone into a slow but consistent decline.[218]

Local tradition attributed the beginnings of tin mining at Ko-chiu to the accidental discovery of cassiterite after the argentiferous galena which was the first object of the miners gave out at depth. Presumably some time afterward – we have no evidence on exactly when – opencast mining began for working the shallower deposits. By the end of the 19th century, both underground mining (*tung chien* 洞尖) and open-pit mining (*tshao phi chien* 草皮尖) were carried on extensively.[219]

211 *TKKW* 14, pp. 240–1; Sun & Sun (1966), p. 251. Marshall D. Draper, who served for a time as chief engineer of the Kotchiu Tin Co., provided early in this century an excellent description of the ores at the large, well-surveyed Malaga (Ma-la-ko 馬拉格) mines: '. . . a common occurrence of the ore is that of linked sausage deposits following usually a more or less well-defined strike. [The strike is the horizontal course or bearing of an inclined deposit.] However, there are also pipe-like deposits, and occasional irregular replacement deposits of large extent where the filling of a cavern makes a really large orebody. . . . A very common occurrence in the Malaga mines is that of beds of from 5 to 30 feet thick, comformable with the bedding planes of the country rock, and thinning out laterally each way from what is evidently the fissure furnishing the mineralising solutions. . . . There are, in addition to this type of orebodies, those branching and ramifying deposits which extend in all directions, which are commonly found in limestone replacement deposits. Sometimes the fissures are well defined, but the tendency of the orebodies as a whole is to make ore along the limestone bedding planes rather than to replace the fissure walls, which are at best not usually well defined.' Draper (1931), pp. 182–3.

212 *Ibid.* 213 *Ibid.* 214 Shih Kuo-heng (1947), p. 57; Bateman (1950), p. 546.

215 Wei Chou-yuan (1946), p. 442.

216 Chhen Ping-fan (*1954*), p. 185. Any of these estimates would be generally consistent with the figures given by Su Ju-chiang (*1942*, p. 31) for the various categories of ore as classified by the Ko-chiu tin miners in the 1930s. The tin content of alluvial deposits ranged from 0.2% to 0.5%, relatively rich for alluvial deposits of cassiterite. Shih Kuo-heng (1947), p. 57; Huang Chu-hsun (*1930*), p. 54.

217 Bain (1933), p. 175. This was undoubtedly due in part to the absence in the Ko-chiu mines of the great enemy of underground mining: water. Miners could thus work to considerable depths, as we shall see in a moment.

218 The great Malaga mine, for example, was closed when I visited Ko-chiu in 1990.

219 Around 1930, there were some 40 lode mines and 200 open-pit workings, with the lode mines accounting for about 90% of the tin produced; Draper (1931), p. 180.

There is very little to distinguish the techniques of underground mining at Ko-chiu from the very primitive techniques that typified most, though not all, of Chinese mining.[220] Tools, for example, consisting largely of hammers, gads, mattocks, hoes and washing pans, were simple and all locally produced.[221] Most shafts were driven at an angle of between 30° and 45° so that the haulers could carry out loads of ore on their backs.[222] Because most of the underground mining took place in ore, the large dumps that usually accompany large mining operations were absent at Ko-chiu.[223] Timbering drew on techniques that were well over 2,000 years old by the late imperial period.[224] Nevertheless, in the ground conditions of Ko-chiu, and especially given the absence of water in the excavations, the techniques were adequate to enable the miners to extend their shafts as much as 1,000 m or more from the surface as measured along their inclined shafts or some 500 to 800 m vertically below the surface.[225]

Overwhelmingly, mining operations at Ko-chiu were carried on in such a way as to minimise capital investment while maximising the use of abundant quantities of low-cost labour. One way to arrive at these complementary goals was to hold down the size of workings, which also had the effect of minimising administrative and management costs. And indeed, much of the mining at Ko-chiu consisted of very small workings carried on by just a few miners or even by a single miner.

Emile Rocher, the French mining engineer who visited Ko-chiu in the 1870s, helps us to understand how this multitude of small workings came about.[226] The first step for anyone or any group desiring to begin a mining operation was to apply to the local authorities for permission. Surprisingly, if Rocher is correct, such permission seems to have been something of a formality and did not even require the payment of any fees.[227]

Authorisation from the local authorities theoretically allowed a miner or group of miners to begin mining *anywhere*, including right in the middle of an area where extensive mining was already taking place.[228] In most cases, however, permission to mine would of course first have to be obtained from a landowner.[229] This permission

[220] For further discussion, cf. below, Section (*h*). [221] Anon. (1926), p. 155.

[222] Draper (1931), p. 182; Collins (1909–1910), p. 188. [223] Draper (1931), p. 180.

[224] Even early in this century, however, they were generally as good as available, or so at least is suggested by the fact that the modern mine first opened by the Kotchiu Tin Co. in 1926 continued to use them; Su Ju-chiang (*1942*), p. 32.

[225] Collins (1909–1910), p. 188; Draper (1931), p. 181. [226] Rocher (1879–1880), Vol. 1, p. 239, fn. 1.

[227] Two possible motivations may have led the authorities to grant such authorisations so liberally: (1) They may have been intent on encouraging as much mining as possible in order to maximise the taxes that they could collect. One would expect this desire to have been particularly strong at the time when Rocher was visiting the area since it had been severely disrupted during the great Muslim uprising from 1856 to 1873. See Rocher 1879–1890, Vol. 1, pp. 234–5 and Collins (1909–1910), p. 187. (2) The authorities also may have felt that, in order to maintain any kind of effective control over the mining areas, they had to at least know who and how many people were engaged in mining operations. Requiring that the miners obtain permission to begin mining but making that permission a mere formality may have been the most effective way of obtaining that information.

[228] This was not necessarily the case in other kinds of mining or mining areas. In the 'coal mining permits' (*tshai mei chih-chao* 采煤執照) system in the Chhing, the location and the boundaries of each mine were, at least in theory, explicitly defined; Lü Tai-ming (*1986*), pp. 143–4.

[229] In imperial China, subsurface minerals rights normally were held by the surface proprietor; this was also the case at Ko-chiu. See Collins (1909–1910), p. 189.

was typically formalised in a lease agreement that spelled out payment terms (*chhou shou* 抽收) and the area in which excavations could be undertaken.[230]

Miners opening a new working in an area where mining was already underway were expected to take care that their workings did not interrupt or hinder the existing workings of their neighbours. This could be very difficult as increasing numbers of excavations crowded a rich area. W. H. Shockley, recalling his experience at some gold–quartz mines near Jehol in Mongolia, claimed to have counted 1,800 shafts in an area 0.8 km (half a mile) square![231] Where the stakes were high and competing groups of miners were evenly matched, underground battles between miners might go on for days.[232] On the other hand, the 'maturing' of a mining area often brought developments that tended to minimise the number of conflicts or the effects of those conflicts that could not be avoided. By the 19th century, some leasing agreements forbade the opening of a new mine on land adjoining an existing mine.[233] Miners' organisations, much resembling the guilds of various kinds so important in the late imperial urban economy, often played a prominent rôle in preventing or resolving disputes.[234] On the basis of his experience at the tin mines of Ko-chiu in the years around 1930, Draper comments that: 'The weight of wealth, precedent, numbers and authority of older owners would be almost certain to allow them to prevail over the newer miners, and this fact probably accounts for the natural reluctance to start any new exploitation shafts and the evident scarcity of such operations in localities known for the extent and ramifications of the deposits underground.'[235] For anyone familiar with the workings of Chinese society, it does not take a great deal of imagination to realise that, in most cases, the miners' organisations were in fact quite thoroughly dominated by the older, well-established mineowners.

Individual workings were also frequently further fragmented by subletting arrangements. Those who held the lease to a particular excavation (*tung chien* 洞尖) might sublease out all or a part of the excavation, say one gallery, or the right to start a new gallery, creating a 'junior excavation' (*tzu chien* 子尖). The holder of the junior excavation might in turn lease all or part of his rights in the form of a 'descendant excavation' (*sun chien* 孫尖).[236] Typically, the lessee of a junior excavation might pay a 'simple sublease fee' (*tan chhou shou* 單抽收) of 3 per cent of the value of the ore excavated. The lessee of a descendant excavation might have to pay a 'double sublease fee' (*shuang chhou shou* 雙抽收) of 6 per cent, by which time there might be

[230] Su Ju-chiang (*1942*), p. 24. Few landowners themselves engaged in mining and few miners purchased the land they mined. Methods of leasing land for mining in most cases probably very much resembled whatever were the customary agrarian tenancy arrangements. See, for example, Zelin (1988), p. 84. Zelin, however, also stresses that, by the 19th century, certain modifications were moving such lease arrangements away from their farming roots. Greater security of tenure was achieved in clauses that allowed for no payment of rent until a mine had begun to produce or that provided for the continuance of a lease until the mineral resource was exhausted or as long as continued production was feasible. See also Section (*l*) fn. 15.

[231] Shockley (1900), p. 603. See also Section (*b*), fn. 12.

[232] Collins (1909–1910), p. 190. Pumpelly (1870, pp. 287–8) tells of extreme cases of bitter battles among miners where the two sides ended up exterminating each other.

[233] Zelin (1988), p. 85. [234] Golas (1977); Rocher (1879–1880), pp. 237–8.

[235] Draper (1931), p. 182. [236] Su Ju-chiang (*1942*), p. 24. On this practice, cf. also Cartier (1967), p. 53.

a half-dozen or more people with claim to some part of the double sublease fee.[237] On occasion, an owner who had leased out an excavation might decide that he wanted to take back the excavation and work it himself. With the agreement of the leaseholder, they could create a 'returned excavation' (*huan chien* 還尖).[238] Wong Lin-Ken's study of tin mining by Chinese miners in Malaysia points out that subletting had the effect of increasing the cost of mining and might, in extreme cases, make uneconomical ore that could otherwise be worked.[239]

Thus, just as Chinese methods of intensive agriculture made maximum use of an abundant labour force, commonly used practices in mining, by maximising the number of workings and giving considerable independence to the miners of galleries off the main shafts and adits, provided working opportunities for a maximum of miners while minimising capital investment.

Not all mining at Ko-chiu, however, was on the small scale we have just described. There were also mines that employed 20, 50 or even over 100 miners.[240] These mines gave ample play to the Chinese talent for elaborate organisation. Typically, the overall supervision of a larger mine would be exercised either by one or more investors in a mine lease (often simultaneously owners of smelters in Ko-chiu who thereby assured themselves a regular supply of ore), by owners of the land on which the mining took place, or, probably most often, by the heads of mining gangs (labour contractors) who leased a working for themselves and the miners they headed or who had been recruited by the investor(s).[241]

Most crucial to the functioning of a larger mine was the general foreman (*shang chhien jen* 上前人) who was himself a miner with long experience and who generally had considerable control over the day-to-day functioning of the mine.[242] He was assisted by foremen (*hsiang thou* 鑲頭) who worked with the miners (usually referred to as 'gravellers' (*sha ting* 砂丁)) and directly supervised the excavating (*cheng khuang* 整埫), setting of supports (*chia hsiang* 架鑲) and the like.[243]

Since so many of the workers came from beyond Ko-chiu and typically returned to their homes in the off season, each new mining season brought a new effort at recruitment. This task was sometimes in the hands of specialist recruiters (*yueh huo thou* 月活頭) who also seem to have exercised general control over their recruits while they worked at the mine, including even forcibly (with the aid of police or soldiers) preventing their running away.[244]

Finally there were the books and records keepers, the 'misters' (*hsien sheng* 先生) who answered to the general foreman.

[237] Su Ju-chiang (*1942*), p. 24; Collins (1909–1910), p. 190. In other mines in Yunnan during the 19th century, the sublease fee could regularly be as high as 10% or even 20%; Wu Chhi-chün (*1845*), ch. 1, p. 18b.

[238] Su Ju-chiang (*1942*), p. 24. [239] Wong Lin Ken (1965), p. 178.

[240] Su Ju-chiang (*1942*), pp. 19–20. [241] Collins (1909–1910), p. 190.

[242] Su Ju-chiang (*1942*), p. 23; Draper (1931), p. 184. He might also be an investor in the mine and/or involved in recruiting miners; Shih Kuo-heng (1947), p. 57. Shih calls the general foremen 'operators'.

[243] *Ibid.*

[244] Su Ju-chiang (*1942*), p. 23. On the other hand, recruiters entrusted with large sums of money sometimes absconded, causing the operators not only a loss of funds but also of needed labourers; Shih Kuo-heng (1947), p. 57.

Even though the porous limestone country rock facilitated ventilation, the very depth of many of the workings made adequate ventilation the major technical problem faced by the miners.[245] It was not uncommon for miners to work in the dark in deep shafts where the oxygen level was insufficient to keep lamps burning. Where mining ultimately had to be discontinued in shafts that still contained workable ore, the major reason was almost always the absence of adequate ventilation.

This was of course no problem in open-pit mining where the techniques were even simpler than those of underground mining. Even open-pit mines, however, sometimes reached a depth of a hundred or so metres.[246] The open-pit workings were typically carried on by groups of seven or eight miners although larger workings might have ten or more.

While certain underground mines were kept in operation year-round, the onset of the rainy season definitively brought to an end opencast mining for that year. Returns for the miners were therefore very much dependent on how well they had estimated the amount of ore they would be able to dress during the rainy season. If too many miners shared the working, producing more ore than could be dressed with the water available that year, the result would be a lower return for each miner. In these circumstances, the inclination was probably quite strong to minimise the number of miners at any given mine and thereby maximise the return per miner.

(iii) *Lead*

Just as happened in the West, early Chinese sometimes confused metallic lead and tin.[247] The two metals appeared very similar, with colour as their main distinguishing characteristic. Tin, being lighter, was often referred to as 'white tin' (*pai hsi* 白錫), and the darker lead as 'black tin' (*hei hsi* 黑錫). This distinction was still in use as late as the Sung.[248]

Even in relatively recent times, the cheaper and difficult to detect lead was used to adulterate rarer and more expensive tin.[249] The adulteration may sometimes have been unintentional, however, resulting from simple misidentification. A modern Peking sample of 'lead' turned out, on testing, to be pure tin![250]

245 Draper (1931, p. 184) argues that the problems of ventilation were exaggerated ('ventilation is usually good and the air is commonly as good as in our deep level mines in the United States') and that the high rate of mortality ('I doubt if it is equaled in any other place in the world') was mainly the result of cave-ins because of the soft ore. But there is every reason to believe that the long-term ill effects of bad ventilation on the health of the miners, which he does not mention, was a serious problem leading to the early death of most miners.

246 Su Ju-chiang (*1942*), p. 30.

247 For example, of the three major tin producing sites listed in the *Hsu Han Shu* (Supplement to the [Former] Han History), one was probably producing lead; Hsia Hsiang-jung *et al.* (*1980*), p. 62. See also Zhu Shoukang (1982), p. 12. Wen Kuang, however, argues persuasively that such confusion has been overstated. He notes that, if it were truly widespread, one should expect to find many lead-bronze objects or tertiary (lead–tin–copper) bronze objects where the proportion of lead was greater than that of tin. In fact, such objects are relatively rare. See Wen Kuang (*1980*), p. 336 and tables on pp. 334–5.

248 Chang Hung-chao (*1927*), p. 312; Hsia Hsiang-jung *et al.* (*1980*), pp. 104, 220. The Romans made a similar distinction between tin and lead, calling tin *plumbum candidum* and lead *plumbum nigrum*; Aitchison (1960), p. 80. On the possible use of *pai hsi* to refer also to zinc, cf. Vol. 5, pt. 2, pp. 214–15.

249 Gillan (1962), p. 296. 250 Read & Pak (1928:1936), p. 7, #10.

It would be a mistake, on the other hand, to assume any such confusion on the part of miners. Since lead never occurs as a native metal in any significant quantities,[251] it could be obtained only from its ores. At least from the Warring States period (−5th to −3th centuries), that meant mainly galena, the common lead sulphide. Miners were hardly likely to confuse galena with cassiterite, the oxide ore that was the source of most Chinese tin.[252] Confusion, insofar as it existed, probably began at the smelting process since both lead and tin melt at relatively low temperatures, can be smelted with similar techniques, and, on cooling, are soft metals similar in appearance. Indeed, some Chinese may well have been misled by what could have been taken as a similar phenomenon, namely green malachite and blue azurite both producing the single metal, copper.[253]

How the Chinese obtained lead before the Warring States period is a complicated question. Surviving texts, not surprisingly, are silent on whatever knowledge of lead and galena Chinese miners, smelters and bronzemakers may have possessed in earlier times. Indeed, Barnard and Satō have pointed to the absence in Shang and early Chou copper/tin/lead bronzes of the appreciable amounts of silver that would be expected if the lead had been derived from galena. They suggest that 'in all probability' the lead was derived from an ore such as cerussite, the lead carbonate.[254] If this was indeed the case, confusion with cassiterite would have been much more possible since cassiterite and cerussite can appear quite similar in colour, lustre, specific gravity, fracture, and crystal structure. The major difference is that cerussite is much softer than cassiterite.[255]

If we follow Barnard and Satō and accept that the Chinese did not exploit galena (or any other sulphide ores) before the −6th or −5th centuries at the earliest, we are led to ask why this was so. China had abundant deposits of galena which, though a sulphide, gives up its metal much more easily than most sulphides.[256] Perhaps even more easily than copper, lead could have been discovered when galena was accidentally melted in a campfire.[257]

[251] Watson (1930), p. 263.

[252] Wen Kuang (*1980*), p. 336. One very good clue to the difference between them would be the tetragonal crystal system of cassiterite compared with the isometric system of galena. Hsia Hsiang-jung *et al.* (*1980*), p. 209 notes that the distinction was in fact clearly made in areas of Hupeh, Honan, Kiangsi and Kwangtung where tin and lead were found associated.

[253] It was my good friend, the late Arnold Siegers, mining geologist and engineer, who first alerted me to the fact that miners could hardly have confused galena and cassiterite.

[254] Barnard & Satō (1975), p. 22, fn. 33 and p. 70. Even in mixed-ore lead–silver deposits, cerussite beds are notorious for their absence of silver; Patterson (1971), p. 312. On the other hand, obtaining lead from galena would have been especially easy because, as Rostoker & Dvorak (1991, p. 18) have proved by experiment, galena differs from most sulphides in that it can simply dissolve in molten copper.

[255] Bauer (1974), nos. 321, 401, 438, 439. Another possible source of lead could have been the sulphate, anglesite, which is often found associated with cerussite; Rosenfield (1965), p. 147; Sorrell & Sandström (1973), p. 240.

[256] Forbes (1954), p. 584; Tylecote (1962), p. 76. See also Aitchison (1960), p. 184: '... galena, when partly converted into oxide by roasting, more or less reduces itself [thus producing metallic lead] when heated to relatively low temperatures.' Actually, nature itself often produces in the caps of lead deposits the mixture of oxidised and sulphide ores that so facilitates reduction; Read (1933), p. 237. Contrast, however, Patterson (1971), p. 310, which argues that the ease with which early metallurgists could have smelted lead from galena has been exaggerated.

[257] Aitchison (1960), p. 43.

It could be that, before the widespread use of coinage beginning around the middle of the −1st millennium, the need for lead was relatively small and the accident of discovery accounted for the use of other ores.[258] It is still not clear whether the lead found in pre-Chou bronzes (and there are many bronzes that have no lead in them) was added intentionally or, as some would argue, entered accidentally from copper ores that contained small quantities of lead.[259] Only when the percentage of lead rises above 8 per cent can we be quite certain that the lead has been added intentionally;[260] in China, it is only with the late Shang or early Chou period that we have a number of bronze objects where the lead content approaches or surpasses this level.[261] In addition to bronzes with relatively high lead content, we also have by at least the late Shang or early Chou objects made of lead, including a dagger-axe (*ko* 戈) of 99.75 per cent pure lead.[262] Most of these were likely non-functional ritual objects but they do suggest that it was probably around the late Shang that, in addition to having been recognised as a useful component of bronze, lead was now coming into use as a metal in its own right.[263]

From perhaps Han times on, Chinese were using pewter, the lead/tin alloy, for a wide variety of utensils. Lead was likewise combined with tin to form a solder, though we do not know when this use was first discovered; it was probably not before the Han.[264]

Apart from the use of lead in alloys (especially for coinage)[265] or as a metal for making a wide range of utensils, the lead oxide litharge was an important component of paints and varnishes, and was also used in external medicines, as was lead carbonate (cerussite).[266] Lead, along with other poisonous minerals such as mercury and arsenic, was not infrequently a part of elixirs to be taken internally.[267] As

[258] Barnard & Satō (1975), p. 22.

[259] Barnard & Satō (1975), pp. 19, 22. Since cupellation was still unknown, about the only significant use for lead was in bronzes to substitute for tin (not very well in terms of the mechanical properties of the resulting alloy) or to contribute to finer castings by lowering the viscosity of a copper/tin alloy; Hodges (1970), p. 127 and Rostoker & Dvorak (1991), p. 17. One special use, though a later one, deserves mention: the bronze arrowheads found in the mausoleum of Chhin Shih Huang Ti 秦始皇帝 have a relatively high lead content, leading Chinese scholars to speculate that the maximum of lead may have been used here to encourage lead poisoning in enemy soldiers wounded by the arrows; Hsia Hsiang-jung *et al.* (*1980*), p. 41.

[260] Gowland (1912), p. 270.

[261] See, for example, the tables in Anon. (*1978b*), pp. 23–4. There is only one example of an early bronze with a very high lead content of 17%. It is one of two large square *ting* 鼎 excavated at Cheng-chou and identified as belonging to the earlier Shang period. Anon. (*1978b*), p. 20. For all the pre-Shang and early Shang lead-containing artefacts known up to 1980, see Sun & Han (*1981*), table 1. (This table is omitted from Murray (1985) as well as from the reprinted version in Anon. (*1986*), pp. 12–25.)

[262] Anon. (*1978b*), p. 25; Hsia Hsiang-jung *et al.* (*1980*), p. 20. Most of whatever lead objects may have been made at this time will have perished because of the susceptibility of metallic lead to corrosion; Rosenfield (1965), pp. 147–8.

[263] Barnard & Satō accept the late Shang as the period when lead 'first appears as an intentional ingredient used in bronze'; Bernard & Satō (1975), p. 70.

[264] Barnard & Satō (1975), p. 100.

[265] Except for the Han period as well as the Ming and Chhing periods after the move to brass coins, Chinese coins typically contained from 10 to 25% lead though shortages of copper and tin especially in the Southern Sung could cause that percentage to rise to 30 and above; Bowman *et al.* (1989), p. 28, figures 2–4.

[266] Hsia Hsiang-jung *et al.* (*1980*), p. 280; Vol. 5, pt. 3, p. 16.

[267] Vol. 5, pt. 2, pp. 291–2; Vol. 5, pt. 3, pp. 78, 196.

mentioned in Vol. 3 (p. 651), much lead went into one of China's oldest chemical industries, the preparation of lead acetate which, as a white paint, was an important cosmetic.[268] Lead also served extensively as a component of many ceramic glazes, as well as in munitions and fireworks.[269] Finally, lead was extensively used in coin alloys throughout the imperial period.[270]

Since most of the silver in China was obtained from argentiferous galena, lead must have become widely available in China from the Thang period on, when silver came to play a very important rôle as a medium of exchange in the Chinese economy.[271] The close association of silver and lead was a most convenient coincidence since lead was needed in the cupellation process for refining gold and silver.[272]

By the Ming and Chhing periods, most of the lead used in China was obtained as a by-product of silver and copper mining, especially in the provinces of Yunnan, Kweichow, Szechwan and Kiangsi (Map 7).[273] If the generalisation of Li Shih-chen is correct, much if not most of that mining was taking place very deep underground.[274]

(iv) *Gold*

Throughout the world, either gold or copper was the earliest metal to be first collected (grubbed) and then mined by humans. Which of the two came to be used first in any particular case can be only a matter of speculation. The excitement attaching to large nuggets of gold – the record seems to be a 86 kg nugget from Australia – can mask the fact that larger and therefore more useable lumps of native copper have always occurred much more frequently than those of native gold.[275] Moreover, as Mark Twain so rightly reminds us, gold is not always easy to recognise (though he is referring in this case to vein gold rather than the placer nuggets that first drew the attention of primitive man).[276] The question then of which metal, gold or copper, was used first (even if only on a very small scale) remains open, all the more since

[268] White lead ink was early used for commenting on texts written in black on wood or bamboo (Vol. 5, pt. 3, p. 17) while lead powder dyed pink served as a kind of rouge from at least the Han onwards (Vol. 5, pt. 3, p. 126).

[269] Vol. 5, pt. 7, pp. 118, 120, 122, 124, 144.

[270] For amounts used in the +18th century, see Vogel (1987a), IV.1. [271] Katō (*1926*).

[272] Vol. 5, pt. 2, pp. 36ff. which discusses the process of cupellation in which the heating of gold and silver (with or without other metals) together with lead in a cupel (i.e., a vessel or shallow hearth) usually made of bone ash results in the bone ash absorbing the lead and the oxides of other metals, leaving behind a cake or globule of the precious metal. See especially the illustration from *TKKW* reproduced on pp. 42–3, with its large cupel.

[273] *PTKM*, ch. 8, p. 12; *TKKW*, ch. 14, p. 241; Sun & Sun (1966), p. 252; Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 603.

[274] *PTKM*; ch. 8, p. 12.

[275] For the Australian nugget, cf. Rickard (1932), p. 94. The largest nugget on record for China was found in the +11th century and weighed 24,500 grams or 53.6 lbs.; in the 1980s, nuggets weighing over 2 or 3 kg were still occasionally found. Cf. Ho Yueh-chiao & Chu Fu-hsi (*1986*), p. 49; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 261. One estimate has it that, across the entire world, perhaps 8,000–10,000 nuggets of gold weighing 10 kg or more have been discovered from earliest times to the present; Chu Shou-Khang & Chang Po-yin (*1989*), p. 65.

[276] '... I learned then, once for all, that gold in its native state is but dull, unornamental stuff, and that only low-born metals excite the admiration of the ignorant with an ostentatious glitter.' Twain (1873), p. 208. Compare also Aitchison (1960), p. 11 and Gettens *et al.* (1969).

there is no necessary reason to believe that the same answer applies to all places and all cultures.[277]

Many scholars, influenced no doubt by gold's long and widespread acceptance as the precious metal *par excellence*, have tended uncritically to read similar attitudes into the thinking of early peoples. This was not necessarily the case. In Africa, gold was little prized compared with copper, which offered a beautiful and evocative reddish colour, warm luminosity and a pleasing sound when struck.[278] This gives us perhaps a clue to help explain one of the most striking facts of early Chinese mining and metallurgy: the almost complete absence of gold in the archaeological record until the middle to end of the –2nd millenium (later Shang) or some thousand years or more after copper and bronze had come into use.[279] Even at this late date, gold was used for the most part only as foil (typically about 0.2 mm in thickness[280]) and leaf (as thin as 0.01 mm[281]) for decorative purposes as a facing material for metal or wooden vessels, implements or ornaments.[282] Chang Kwang-chih, noting that Shantung could have been a source of significant amounts of gold, suggests that '[t]he rarity of gold [in the Shang] can only be read in terms of the Shang's own values.'[283]

Cast or worked objects do not appear in any significant numbers for another half of a millennium after the Shang.[284] Only around –500 can we say with some confidence that gold had become *the* luxury metal in China, a reliable indicator of the power and prestige of those who owned it.[285]

We have discussed above (Section (*d*)(2)(ii)) the weathering of primary ore deposits which frequently transforms the original sulphide deposits into native metals.[286] Further breakdown of the deposit and transport of its materials can produce

[277] Here we might also note Noel Barnard's suggestion that gold may not even have been discovered by the Chinese until long after they had begun to produce bronzes from mixed ores, and even after they had already recognised the cassiterite found in placers as a source of tin; Barnard (1989), p. 191, fn. 32. This hypothesis does not appear very promising, given the ease with which nuggets of gold can often be recognised. That gold was 'useless for anything but ornament' may, together with the fact that it was rarely available in any quantity, help account for its limited *use* in the early stages of Chinese knowledge of metals, but that is not likely to have delayed its *discovery*. For the paucity of gold remains that can be dated to even the Shang dynasty, cf. Lu Pen-shan & Wang Ken-yuan (*1987*), p. 73.

[278] Herbert (1984). [279] Chao Khuang-hua (*1990*), p. 245.

[280] Barnard & Satō (1975), p. 69, fn. 83; Franklin (1983), p. 290.

[281] Anon. (*1978b*), pp. 34–5; Li Chung-chün (*1982*), p. 1. Ho Yueh-chiao & Chu Fu-hsi (*1986*, p. 147) speak of leaf as thin as 1/10,000 of a mm, in which case 30 grams can provide enough gold for a sheet of nine square metres.

[282] Andersson (1935), pp. 6–7; Chang Kwang-chih (1980), p. 157; Barnard & Satō (1975), pp. 69 and 96. Keightley (1983, pp. 250, fn. 16 and 290–1) notes that metal-bearing sites in China up to the Shang at least show no use of gold *or any other metals* as objects of personal ornament. Undoubtedly this was due to the unique importance attached to jade and jade-like stones in early China.

[283] Chang Kwang-chih (1980), p. 157. Ursula Franklin, referring to the use of gold leaf in the Shang, has suggested that, in early times, 'what is surprising is the almost trivial use to which [gold] was put. . . . gold sheets were [apparently] used mainly for their contrasting colour.' Franklin (1983), p. 290. She concludes that 'gold conveyed beauty, but not necessarily status'. Emma Bunker, on the other hand, usefully distinguishes between gold itself reflecting status (not the case in the Shang) and the use of gold to enrich artefacts that reflected status (clearly true for the Shang); Bunker (1993), p. 27. That might make its use somewhat less 'trivial'.

[284] Barnard & Satō (1975), p. 68. [285] Bunker (1993), pp. 29, 35.

[286] A native element is one that occurs in the free state, that is, not *chemically* combined with any other element. This means that it can be used once it is mechanically separated, if necessary, from its matrix (in the case of gold, typically quartz or quartzite). In alluvial deposits, this mechanical separation has often been accomplished by weathering, the tumbling action in the stream, etc.

concentrations of these native metals on hillsides and in watercourses. Native gold and copper, often quite easy to recognise, were thus present as nuggets in many of the same stream beds where primitive man chose the stones he used for tools.[287] These pieces of gold and copper could be used just as they were found (without being smelted), with perhaps minor mechanical modification (hammering into shape, perforating).

There are two basic kinds of gold deposits: vein deposits and placer deposits.[288] From at least Warring States times (latter −1st millennium), placer gold was regularly referred to as 'sand gold' (*sha chin* 沙金) while gold in veins was usually called 'mountain gold' (*shan chin* 山金).[289] Vein deposits regularly consist of elemental gold, almost always with at least a small admixture of silver, mechanically combined with quartz so that the gold can be obtained by crushing the ore and 'washing' it to separate out the gold.[290] Alternatively, amalgamation could be used to separate out gold from sands or a crushed matrix, though Edward Schafer believed that even as late as the Thang, this may have been a secret process known by alchemists ('Taoists') but unknown to miners.[291]

Placer deposits typically contain flakes, dust ('flour') or grains of native gold (*sheng chin* 生金), often very nearly pure because most of the silver originally present has dissolved out. Sometimes a placer will contain nuggets of some size though typically smaller than nuggets or pieces of native copper.[292] On the other hand, pieces of gold (unlike copper) can be joined in a good weld simply by hammering the pieces together.[293] The small size of early objects made of gold was therefore probably due to the limited availability of accessible pieces of gold.[294]

In China, rich gold deposits are often to be found in the metamorphosed pre-Cambrian (570+ million years ago) granite so prominent in many of China's major mountain ranges: the Wu-thai 五台 and Lü-liang 吕梁 mountains in Shansi, the An-shan 鞍山 mountains in Liaoning, the Hei-lung-chiang 黑龍江 mountains, the Thai-shan 泰山 range in Shantung, the Sung-shan 嵩山 mountains in Honan (Map 8).

[287] Easy to recognise in their own right, though it would be a long time before they would be recognised as components of a much larger category, 'metals'. On the important question of how early humans came to recognise the category 'metals', see Franklin (1983), pp. 281–2 and Rickard (1932), pp. 163–4. Multhauf (1965, p. 142, n. l) points out that it was only around the time of Christ that the word 'metal' was limited in the West to those substances we think of as metallic.

[288] Cf. above, Section (*d*)(2).

[289] *Shan chin* 山金 was also used more broadly to signify any gold to be found in the mountains, including that found in eluvial deposits (where the weathered material or 'float' is still near or at its place of formation) and bench placer deposits (original alluvial placer deposits that later form dry terraces or ledges on a mountain side); Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 260. See Li Chung-chün (*1982a*) for a discussion of traditional terms relating to gold mining together with a good selection of texts in which they appear.

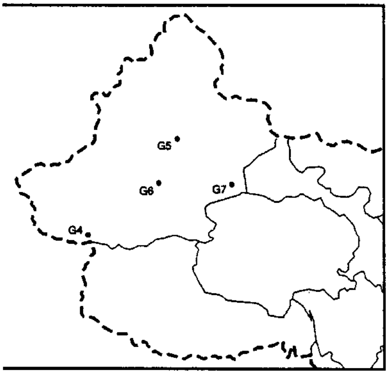
[290] For further discussion of this process, cf. below, Section (*g*). The natural alloy of gold and silver, electrum, was called by the Chinese 'yellow silver' (*huang yin* 黃銀), 'pale gold' (*tan chin* 淡金) or 'gold-silver stone' (*chin yin shih* 金銀石). For Chinese methods of separating the gold and silver in electrum before nitric acid first began to be imported into China in the +18th century, see Chao Khuang-hua (*1990*).

[291] Schafer (1963), p. 251. Actually, amalgamation was in use by the end of the Han; Sivin (1978), p. 461.

[292] The late +12th century *Ling Wai Tai Ta* speaks of gold nuggets in far southern China as large as hen's eggs which the inhabitants referred to as 'gold mother' (*chin mu* 金母); finding one made a person rich. *Ling Wai Tai Ta*, ch. 7, p. 10a; Netolitzky (1977), p. 128.

[293] Also in contrast to copper, gold does not harden and thus crack easily when hammered.

[294] Hodges (1970), p. 53.



Map 8. Pre-20th century gold mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A Liaoning	H Kiangsu	P Hunan
B Hopeh	J Anhwei	Q Szechwan
C Shantung	K Honan	R Kweichow
D Shansi	L Chekiang	S Kwangtung
E Shensi	M Fukien	T Kwangsi
F Kansu	N Kiangsi	U Yunnan
G Sinkiang	O Hupeh	V Kirin

Caption to Map 8. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 8

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
A4	Ta-ning	大寧	Ning-chheng	寧城					X	
A5	Lung-shan hsien	龍山縣	Ling-yuan	凌源					X	
A6	Shuang-chheng	雙城	Thieh-ling	鐵嶺					X	
A7	Hei-shan	黑山							X	
B8	Tun-hsing shan	敦興山	Lin-chheng	臨城	X					
B11	Shan-chou	擅州	Phu-yang	濮陽					X	
B12	Ching-chou	景州	Tshang-chou	滄州					X	
B13	Chhien-an	遷安							X	X
B14	Feng-jun	豐潤								X
C11	Thai-shan	泰山	Thai-an	泰安	X					
C12	Teng-chou	登州	Pheng-lai	蓬萊				X	X	
C9	Lai-chou	萊州	Yeh-hsien	掖縣				X	X	
C10	I-tu	益都							X	
C13	Tzu-chou	淄州	Tzu-chhuan	淄川					X	
C14	Hsi-hsia hsien	栖霞縣							X	X
C15	I-chou Pao shan	沂州寶山	Lin-i	臨沂					X	
C16	Lai-yang	萊陽							X	X
C7	Chiao-chou	膠州							X	
C17	Chao-yuan	招遠							X	X
C18	Wen-shang	汶上								X
C4	Lin-chhü	臨朐								X
C5	Chü-chou	莒州								X
D21	Ti-tu shan	帝都山	Yang-kao	陽高	X					
D22	Liang-chhü shan	梁渠山	Yang-kao	陽高	X					
D23	Ku-thi shan	鼓題山	Yang-kao	陽高	X					
D24	Thai-hsi shan	泰戲山	Fan-chih	繁畤	X					
D1	Shao-shan	少山	Hsi-yang	昔陽	X					
D25	Yeh-li shan	謁戾山	Hsi-yang	昔陽	X					
D26	Meng-men shan	孟門山	Chi-hsien	吉縣	X					
D19	Huai-shan	槐山	Wen-hsi	聞喜	X					
D27	Huan-shan	洹山	Chang-tzu	長子	X					
D28	Thai-yuan	太原					X			
D29	Wei-chou	緯州						X		
D30	Hsin-chou	忻州							X	
E24	Ying-shan	英山	Wei-nan	渭南	X					
E25	Chhin-mao shan	秦冒山	Fu-shih	膚施	X					

Key to Map 8 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
E26	Shu-li shan	數歷山	Chhien-yang	千陽	X					
E27	Lung-shou shan	龍首山	Hsi-an	西安	X					
E6	Yang-hsu shan	陽虛山	Lo-nan	洛南	X	X				
E3	Yang-hua shan	陽華山	Hua-yin	華蔭	X					
E21	Chhi-shan	岐山	Feng-hsiang	鳳翔	X					
E28	Shen-shan	申山	An-sai	安塞	X					
E20	Han-chung	漢中				X				
E29	Hsi-chheng	西城	An-khang	安康			X			
E30	Han-yin	漢蔭					X			
E31	Chin-chou	金州	An-khang	安康				X		
E32	Shang-chou	商州	Feng-yang hsien	豐陽縣				X		
E13	Lan-thien	藍田							X	
E14	Hsien-ning	咸寧							X	
E15	Chou-chih	周至							X	
E16	Chhang-an	長安							X	
E33	Hsi-hsiang	西鄉							X	
E34	Hsing-an chou	興安州							X	
F3	Hui-chiang shan	槐江山	Chang-yeh	張掖	X					
F3	Thien-shan	天山	Chang-yeh	張掖	X					
F4	Wen-chou	文州					X			
F5	Lan-chou	蘭州					X			
F6	Tang-chou	宕州	Min-hsien	岷縣			X			
F7	Su-chou	肅州	Chiu-chhüan	酒泉			X			
F8	Chhü-shui	曲水					X			
F9	Huai-tao	懷道					X			
F10	Fu-lu	福祿					X			
F11	Yü-men	玉門					X			
F3	Kan-chou	甘州	Chang-yeh	張掖						X
F12	Tun-huang	敦煌								X
G4	Ho-chou	和州	Thu-lu fan	吐魯番					X	
G5	Tha-chheng	塔城								X
G6	I-li	伊犁	Sui-ting	綏定						X
G7	Wu-lu mu chhi	烏魯木齊								X
H1	Chiang-tu	江都					X			
H11	Pao-ying	寶應							X	
J16	Hsi-chou	歙州						X		
J17	Hui-chou	徽州							X	
J18	Chhih-chou	池州	Kuei-chhih	貴池					X	
K17	Ju-ho	汝河			X					
K3	Hsien-shan	鮮山	Sung-hsien	嵩縣	X					
K1	Thai-hang shan	太行山	Hui-hsien	輝縣	X					
K1	Chü-ju shan	沮洳山	Hui-hsien	輝縣	X					
K18	Hou-shih shan	猴氏山	Yen-shih	偃師	X					
K7	Yi-ti shan	倚帝山	Chen-phing	鎮平	X					
K19	Kao-chhien shan	高前山	Nei-hsiang	內鄉	X					
K19	Chi-wang shan	冀望山	Nei-hsiang	內鄉	X					
K4	Feng-shan	豐山	Nan-yang	南陽	X					
K4	Ya-shan	雅山	Nan-yang	南陽	X					

Key to Map 8 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
K20	Yi-su shan	宜蘇山	Meng-chin	孟津	X					
K21	Lu-thi shan	鹿蹄山	I-yang	宜陽	X					
K22	Lou-cho shan	婁涿山	Lo-ning	洛寧	X					
K23	Chan-chu shan	瞻諸山	Lo-yang	洛陽	X					
K24	Chhang-shih shan	長石山	Hsin-an	新安	X					
K25	Tho-shan	橐山	Shan-hsien	陝縣	X					
K26	Mo-shan	沬山	Chung-mou	中牟	X					
K27	I-shan	役山	Cheng-chou	鄭州	X					
K10	I-yang	伊陽					X			
K8	Le-an	樂安	Kuang-shan	光山			X			
K28	Huai-chou	懷州	Chhin-yang	沁陽					X	
K29	Meng-chou	孟州							X	
K30	Tshai-chou	蔡州	Ju-nan	汝南					X	
K31	Kung-hsien	鞏縣							X	
L19	Chü-yü shan	句餘山	Yu-yao	餘姚	X					
L15	Hui-chi shan	會稽山	Shao-hsing	紹興	X					
L17	Lin-hai	臨海					X			
L18	Lung-chhüan	龍泉								X
M18	Chiang-le	將樂					X			
M19	Hou-kuan	侯官					X			
M9	Thing-chou	汀州						X		
M5	Chhang-thing	長汀							X	
M20	Fu-an	福安							X	
M21	Ning-te	寧德							X	
M22	Phu-chheng	浦城	Ma-an shan	馬鞍山					X	
N19	Yü-chang Pho-yang	豫章鄱陽	Po-yang	波陽		X	X			
N5	Le-phing	樂平					X		X	
N8	Shang-jao	上饒					X			
N20	Lin-chhuan	臨川					X			
N21	Yü-tu	雩都					X			
N4	Jao-chou	饒州	Po-yang	波陽				X	X	
N20	Fu-chou	撫州	Lin-chhuan	臨川				X		
N9	Nan-an chün	南安軍	Ta-yü	大庾				X		
N22	Hsin-chou	信州	Kuei-hsi hsien	貴溪縣				X	X	
N23	Lung-hsing	龍興	Lin-ju	臨汝					X	
N24	Fu-chou	撫州	Le-an hsien	樂安縣					X	
N25	Hsin-chien	新建							X	
O30	Han-shui	漢水			X					
O31	Ching-shan	荊山	Nan-chang	南漳	X	X				
O32	Chang-shui	漳水	Tang-yang	當陽	X					
O33	Ching-shan	景山	Fang-hsien	房縣	X					
O34	I-ling	夷陵	I-chhang	宜昌			X	X		
O35	Chhing-chiang	清江					X			
O12	Shih-chou	施州	En-shih	恩施			X			
O36	Fang-chou	房州						X		
O37	Chiang-ling	江陵							X	
O38	Hsiang-yang	襄陽							X	
O7	Nan-chang	南漳							X	X
O39	I-chheng	宜城							X	X

Key to Map 8 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
O40	Chien-shih	建始							X	
O1	Ta-yeh	大冶								X
O41	Shih-shou	石首								X
P2	Chao-yao shan	招搖山	Kuei-yang	桂陽	X					
P24	Tung-thing shan	洞庭山	Yueh-yang	岳陽	X					
P1	Chhang-sha	長沙					X			
P8	Heng-chou	衡州					X	X		
P25	Hsu-chou	敘州	Chhien-yang	黔陽			X			
P26	Hsiang-yuan	湘源					X			
P27	Hsiang-hsiang	湘鄉					X			
P28	Lung-piao	龍標					X			
P29	O-shan	峨山					X			
P30	Yueh-chou	岳州	Phing-chiang hsien	平江縣				X	X	
P31	Yuan-chou	沅州	Chih-chiang	芷江				X	X	
P32	I-yang	益陽						X		X
P33	Ching-chou	靖州							X	X
P34	Chhen-chou	辰州							X	
P5	Than-chou	潭州							X	
P35	Wu-kang	武岡							X	
P36	Pao-chhing	寶慶	Shao-yang	邵陽					X	
P37	Wu-ling	武陵	Chhang-te	常德					X	X
P38	Yuan-ling	沅陵							X	X
P39	Hsu-phu	溆浦							X	
P40	Chhüan-chou	全州							X	
Q35	Min-shan	岷山	Mao-hsien	茂縣	X					
Q3	Lai-shan	崍山	Ying-ching	滎經	X					
Q36	Chia-meng	葭萌	Chao-hua	昭化		X				
Q4	Han-chia	漢嘉	Ya-an	雅安		X				
Q37	Hsuan-han	宜漢					X			
Q38	Pa-hsi	巴西					X			
Q39	O-mei	峨嵋					X			
Q40	Nan-phu	南浦					X			
Q41	Lin-chiang	臨江					X			
Q42	Mien-ku	綿谷					X			
Q43	Hua-chheng	化城					X			
Q44	Pheng-shui	彭水					X			
Q45	Wen-chiang	溫江					X			
Q46	Thang-an	唐安					X			
Q47	Lung-yu	龍游					X			
Q48	Tung-i	通義					X			
Q7	Yang-an	陽安					X			
Q49	Chin-shui	金水					X			
Q50	Phan-shih	盤石					X			
Q51	Tzu-yang	資陽					X			
Q52	Nei-chiang	內江					X			
Q53	Thai-teng	臺登					X			
Q8	Lu-shan	盧山					X			
Q54	Wen-shan	汶山					X			
Q55	Tso-feng	左封					X			
Q56	Ting-lien	定廉					X			
Q57	Wei-chheng	魏城					X			
Q58	Phu-an	普安					X			

Key to Map 8 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
Q59	Shih-ching	石鏡					X			
Q60	Chiang-yu	江油					X			
Q61	Jen-shou	仁壽					X			
Q62	Chi-hsien	籍縣					X			
Q63	Hsu-chhuan	旭川					X			
Q64	Lu-chhuan	瀘川					X			
Q65	Mei-chou	眉州						X		
Q17	Chia-chou	嘉州	Le-shan	樂山				X		
Q31	Ya-chou	雅州						X		
Q66	Chien-chou	簡州						X		
Q67	Tzu-chou	資州						X		
Q68	Chhang-chou	昌州	Ta-tsu	大足			X	X		
Q29	Li-chou	利州	Kuang-yuan	廣元				X		
Q69	Lung-chou	龍州	Phing-wu	平武				X		
Q70	Wan-chou	萬州						X		
Q71	Chheng-tu	成都							X	
Q72	Chia-ting	嘉定							X	
Q73	Lo-lo	羅羅							X	
Q14	Hui-chhuan	會川	Hui-li	會理					X	
Q18	Chien-chhang	建昌							X	
Q74	Te-chhang	德昌							X	
Q22	Pai-hsing	柏興	Yen-yuan	鹽源					X	
Q28	Lung-an fu	龍安府	Phing-wu	平武			X		X	
Q75	Ho-hsien	合縣							X	
Q76	Chung-hsien	忠縣							X	
Q77	Ta-tsu	大足							X	
Q78	Wan-hsien	萬縣							X	
Q79	Thung-chhuan	潼川	San-thai	三台					X	
Q80	Kuan-yuan	廣元							X	
Q81	Fu-ling	涪陵					X		X	
Q82	Pa-chou	巴州	Pa-chung	巴中					X	
Q83	Pao-ning fu	寶寧府	Lang-chung	閬中					X	
Q30	Chien-chou	劍州	Chien-ko	劍閣					X	
R4	Thung-jen tai phing hsi	銅仁太平溪							X	
R9	Sheng-hsi	省溪							X	
R10	Thi-hsi	提溪	Chiang-khou	江口					X	
R11	Thien-chu	天柱								X
R12	Ssu-nan	思南								X
R13	Chen-yuan	鎮遠								X
S2	Lien-shan	連山					X			
S39	Ssu-hui	四會					X			
S40	Tuan-hsi	端溪					X			
S41	Hsin-hsing	新興					X			
S42	Thung-ling	銅陵					X			
S43	En-phing	恩平					X			
S44	She-chheng	舍城					X			
S45	Chhiung-shan	瓊山					X			
S46	Ning-yuan	寧遠					X			
S47	Hun	義倫					X			
S48	Wan-an	萬安					X			
S49	Chhin-chiang	欽江					X			
S50	Nan-en chou	南恩州						X		
S51	Li-yeh shan	林冶山	Ling-shan hsien	靈山縣					X	

Key to Map 8 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
T7	Yung-chou	邕州					X			
T24	Hsiang-yuan	湘源					X			
T18	Shang-lin	上林					X			
T25	Ning-phu	寧浦					X			
T26	Kuei-phing	桂平					X			
T27	Yung-ting	永定					X			
T11	Yü-lin	鬱林					X			
T28	Yang-shou	陽壽					X			
T29	Chhang-le	常樂					X			
T30	Li-shan	立山					X			
T31	Jung-shui	融水					X			
T32	Po-pai	博白					X			
T33	Chhang-lin	常林					X			
T34	Fu-an	撫安					X			
T21	Hsuan-hua	宣化	Yung-ning	邕寧			X		X	
T6	Tshang-wu	蒼梧								X
T35	Huai-chi	懷集								X
U43	Chi-shan	雞山	Yung-phing	永平	X					
U43	Po-nan	博南	Yung-phing	永平		X				
U44	Tien	滇				X				
U3	Ai-lao	哀牢				X				
U45	Yao-chou	姚州	Yao-an	姚安			X			
U46	Wei-chhu	威楚							X	
U22	Li-chiang	麗江							X	
U4	Ta-li	大理							X	
U11	Chin-chhih	金齒							X	
U47	Lin-an	臨安							X	
U48	Chhü-ching	曲靖							X	
U18	Yuan-chiang	元江							X	
U8	Wu-sa	烏撒	Chen-hsiung	鎮雄					X	
U5	Tung-chhuan	東川							X	
U49	Wu-meng	烏蒙	Chao-thung	昭通					X	
U50	Chin-sha chiang	金沙江							X	
U10	Yung-ning	永寧							X	
U51	Lan-tshang chiang	瀾滄江							X	
U52	Yao-an	姚安							X	
U53	Yung-chhang	永昌								X
U29	Theng-yueh	騰越								X
U21	Yung-pei	永北								X
U54	Khai-hua	開化								X
U55	Chung-tien	中甸								X
V1	Khai-yuan	開元	Nung-an	農安					X	

In these areas, gold and iron are often associated in shallow deposits in argillaceous (clays, shales, mudstones) and silica-rich rock formations. Other important deposits are found in Szechwan, Hopeh and Kiangsi and the gold belt to the south of Kuei-lin 桂林 in Kwangsi.[295]

Placer deposits have probably been mined in every province of China.[296] Usually, they are shallow and meagre. In Fukien, Kiangsi, Hupeh, Hunan, Kwangtung, Kwangsi, Szechwan and, especially, Yunnan and Heilungkiang, however, they have been of somewhat greater richness and importance.[297] In the early part of this century, placer mining was so dominant in Chinese gold-mining that the ordinarily well-informed pioneering Chinese geologist, Wong (Weng) Wen-hao 翁文灝, could write that 'It is the gold-bearing alluvial deposits that constitute up to the present, the only source of [gold] production in China.'[298] In many areas, extensive placer mining is still carried on using traditional methods.[299]

In the geological processes of formation, vein deposits of course precede placer deposits, which derive from them. The exploitation of gold deposits, however, took the opposite course. Because gold is one of the heaviest metals, concentrating it by washing (gravity separation) is one of the easiest of all forms of mining.[300] Placer deposits were therefore exploited long before vein deposits.[301] Archaeological remains reveal that the inhabitants of the Kansu area recognised and used placer gold at least as early as the first half of the –2nd millennium.[302] But it is still an open question when the Chinese first began to mine primary vein gold.[303] The scattered evidence assembled by Lu Pen-shan 卢本珊 and Wang Ken-yuan 王根元, shows that the Chinese had begun underground mining of gold in some areas perhaps as early as the Eastern Han but, in any case, by the Sui period at the latest.[304] Actually, even the Eastern Han date may be too conservative. In the *Discourses on Salt and Iron*

[295] Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 260 and 266–7. By the Thang period, gold mining had also acquired some importance in Yunnan; Yoshida (*1967*), p. 236. For an exhaustive treatment of China's gold deposits, see Chang Chen-ken *et al.* (*1988–1992*).

[296] Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 260; Bain (1933), p. 157. This reminds us that, in China as elsewhere, gold is almost as widely distributed as iron (Wong Wen-hao (1920), p. 53; Rickard (1932), p. 93). In the *SHC*, as Donald Wagner points out (1993, p. 249), gold is mentioned more often than all the other minerals combined. Of course, gold deposits are typically much smaller than iron deposits. Still, given the virtual imperishability of gold (for reasons, cf. Young (1970), p. 106), weathering of gold-bearing rock and concentration of even minute amounts of gold can produce economically workable accumulations.

[297] Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 260; Chang Hung-chao (*1954*), pp. 2–3; Anon. (*1978b*), p. 34, fn. 1; Torgasheff (1930), p. 121. *TKKW* claims that, by the Ming, Yunnan was the leading placer gold-producing region in China: *TKKW* 14, p. 233 (Sun & Sun (1966), p. 236). The Chin-sha River 金沙江 in Yunnan was especially rich in alluvial gold so that the gold concentrated on rocks in the river could be collected even without washing; Chu Shou-Khang & Chang Po-yin (*1989*), p. 64.

[298] Wong Wen-hao (1920), p. 53. For specific examples of underground gold mining, cf. Table 13 below; Couling (1917), p. 369; Anon. (1915), p. 14. By far the great majority of China's placer deposits are alluvial; eluvial and bench deposits are of secondary significance. Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 261.

[299] For interviews with two present-day gold miners at Phing-ku 平谷, some 45 km southeast of Peking, as well as with a peasant who would have nothing to do with mining, cf. Zhang & Sang (1987), pp. 145–9.

[300] Rickard (1932), pp. 94–5. [301] Cf. below, Section (*g*).

[302] Lu Pen-shan & Wang Ken-yuan (*1987*), p. 73; Hsia Hsiang-jung *et al.* (*1980*), p. 298.

[303] Hsia Hsiang-jung *et al.* (*1980*), pp. 304–5.

[304] Chu Shou-Khang & Chang Po-yin (*1989*), p. 65; Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 262–3; Lu Pen-shan & Wang Ken-yuan (*1987*), p. 76. See also Chu Shou-Khang & Chang Po-yin (*1989*), p. 64.

(*Yen Thieh Lun* 鹽鐵論), from the −1st century, the literati note that, in those days of growing extravagance, '[miners] dig into mountain rocks to obtain gold and silver (*tsuan shan shih erh chhiu chin yin* 鑽山石而求金銀)'.[305] This appears to refer to at least shallow excavation of vein deposits rather than to the working of placers.

An interesting early reference to underground mining of gold discusses the famous gold mining district on the northern side of the Shantung peninsula, centred on the present-day Yeh hsien 掖縣 and Mou-phing hsien 牟平縣. According to the +9th century *Yuan-ho Chün Hsien Chih* 元和郡縣志 (Gazetteer of the Provinces and Counties of the Yuan-ho Reign-period [+806 to +820]): 'The electrum (*huang yin* 黃銀) mine of Chhang-yang hsien is located 140 *li* east of the city. In the 18th year of Khai-huang of the Sui (+598), the prefect of Mou-chou, Hsin Kung-i, "smelted" electrum (*yeh chu te huang yin* 冶鑄得黃銀) at this mine and presented it to the court.'[306] One wonders if this might describe an alternative to crushing and washing gold ore: in heating a quartz ore, the electrum (native gold containing significant percentages of silver) would melt before the quartz and could therefore be drained off. On the other hand, we may just possibly be looking at a reference to the roasting or smelting of a telluride ore though the recognition of gold tellurides and sulphides seems to be only a very recent development in Chinese mining.[307] A third possibility is that the text refers to a process still being used for working gold in this century: the ore is heated and quenched to make it brittle and thus easier to grind, after which it could be washed to obtain the electrum.[308] Finally, this text could refer to a refining process that did not separate the gold and silver but removed other trace elements such as copper.

It would be especially helpful to be able to identify the process indicated here because the practice of underground mining of gold does not necessarily imply the mining of vein ores. Miners have sometimes found buried at some depth ancient placer deposits of native gold that had been covered up in later epochs (Fig. 10). A good example was the Hsi-hsia gold mine at Teng-chou in Shantung, the largest gold mine of the Yuan period, where gold-bearing gravel on a pre-Cambrian bedrock had been covered with basalt from the relatively recent Pliocene period (c. 2 million years ago).[309] Thus, although we have here underground excavation, it did not involve the mining of vein gold.

Given the significant increase in the use of gold beginning around the middle of the −1st millennium (Fig. 11) it seems likely that there was quite considerable gold mining being carried on in many parts of China by that time.[310] In the Han, for the only time in Chinese history, gold bullion was not only extensively used in commercial transactions[311] but was even more prevalent than silver.[312] Even the early

[305] *Yen Thieh Lun*, ch. 3, p. 21; Gale (1967), p. 21. [306] Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 265.

[307] Lu Pen-shan & Wang Ken-yuan (*1987*), p. 73.

[308] Read (1907), p. 1297. Read notes the 'striking similarity' of this method to practices in Europe in the +15th century.

[309] Hsia Hsiang-jung *et al.* (*1980*), p. 304; Schurmann (1956), p. 154.

[310] Huang Yü-heng & Ai Ta-chheng (*1989*), pp. 11–16. [311] Yang Lien-sheng (1952), pp. 16, 43.

[312] Dai Zhiqiang (Tai Chih-chhiang) and Zhou Weirong (Chou Wei-jung) have recently suggested that one of the reasons why the Chinese never developed a tradition of minting gold (or silver) coins was because the precious metals were still scarce in north China in the middle of the −1st millennium when coinage came into wide use.

Fig. 10. The mining of deep gold gravels in Ethiopia. If the ground is reasonably firm, shafts can be excavated, using simple methods, to reach the bedrock. United Nations (1972), p. 51, fig. III. The *Thien Kung Khai Wu* 天工開物, ch. 14, p. 233 may refer to something like this when it says, referring to the mining of 'flour-like (fine) sand gold' (*mien sha chin* 麵砂金), that 'they dig shafts (*ching* 井) into level ground to obtain it'. (Contrast translation in Sun & Sun (1966), p. 236.) Such a procedure is even more strongly suggested by the remains of bench placer working in the I-yang 益陽 area of Hunan and in the more than 1,000 surviving 5–6 metre deep old shafts in the Heng-yang 衡陽 area of the same province; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 268.

Fig. 11. Gold coins (?) bearing inscriptions 'treasure of [the Chhu capital of] Ying' (*Ying-yuan* 郢爰) or 'treasure of Chhen' (*Chhen-yuan* 陳爰). Anon. (1972), pl. 70. The gold is up to 99% pure; Hsia Hsiang-jung *et al.* (*1980*), p. 40; Chu Huo (*1983*), p. 30. Such coins have been excavated in at least seven modern provinces; Chhen Erh-chün (*1995*), p. 259.

Han government seems to have had remarkably large amounts of gold available to it.[313] Thus, for example, Emperor Wu 武 could in −123 reward troops that had been successful against the Hsiung-nu 匈奴 tribes to the north with something over one and one-half million ounces of gold![314] On the death of Wang Mang 王莽 in +23, the central treasuries alone are reported to have amassed some 700,000 *chin* or about 156 tonnes of gold, estimated to be more than all the gold available in medieval Europe.[315] It is hardly surprising then that gold also came to be widely used among the wealthy and powerful for functional items such as utensils and buttons.[316]

Unfortunately, presently available information provides us with virtually no evidence to answer the question of most interest here: how much of the availability of considerable amounts of gold by Han times can be explained by advances in the technology of gold mining? Indeed, as suggested above, we cannot exclude the possibility that some, even much, of that gold may have entered China from outside,

313 It has been suggested that the *huang chin* 黃金 in Han sources may refer to copper instead of gold, but this appears unlikely; Chhen Chih (*1955*), p. 101.

314 Goodrich (1963), p. 40; Vol. 5, pt. 2, p. 50.

315 Huang Yü-heng & Ai Ta-chheng (*1989*), p. 25; Dubs (1942), pp. 36–9, cited in Goodrich (1963), p. 40 and Vol. 5, pt. 2, p. 50.

316 Chhen Chih (*1955*), p. 101. For other examples of the availability of large amounts of gold, cf. Hsia Hsiang-jung *et al.* (*1980*), p. 56. Loewe is inclined to believe that the gold of the Han was produced in China and not, as some have suggested, imported in significant quantities; Loewe (1985), p. 263. Compare Vol. 5, pt. 2, p. 50.

for example by way of Siberia or through the growing trade with central Asia along what would come to be known as the Silk Road.[317] Alternatively, extensive underground mining of gold veins, if it had begun by this time, could have significantly increased the supply of gold. Here, too, we simply do not know. In placer mining, a potentially important advance that could have had a significant effect on gold production would have been the introduction of sluices, which some scholars claim have been found in the Thung-lü shan 銅綠山 copper mine excavations. A recent article even refers to 'a gravity separator chute'.[318] Given that simple panning of gold has remained the overwhelmingly dominant method of working gold placers right down to the present,[319] however, the likelihood would seem to be that any significant increases in placer gold production occurring during the Warring States and Han periods owed more to discoveries of new deposits and increases in the number of people engaged in gold washing rather than to technological breakthroughs.

Chhen Chih argues that gold became increasingly scarce in the course of the Han and later, attributing this growing scarcity to the gradual exhaustion of many of the most easily worked deposits as well as a siphoning off of much gold into the gilding of Buddhist statuary.[320] Katō Shigeshi also notes a post-Han increase in the use of gold for utensils and jewellery[321] which must have very significantly increased demand for and therefore the value of gold. He also draws attention to Chao I 趙翼's comment in his *Kai Yü Tshung Khao* 陔餘叢考 (Collected Researches While on Leave from Official Duties) that, from the late Six Dynasties period, gold and silver amounts are increasingly given in *liang* 'ounces' rather than in the much larger *chin*, which also suggests a rising value for gold and silver.[322]

(v) *Silver*

By comparison even with gold and copper, native silver occurs very rarely in nature.[323] Moreover, silver combines easily with acids to form soluble compounds that are carried off during erosion. It is therefore rarely met with in easy-to-work placer deposits but must be won from underground veins.[324] Finally, what native

[317] For an excellent, up-to-date discussion of early contacts between Chinese and non-Chinese peoples as they may relate to the use of gold, see Bunker (1993).

[318] Zhou Baoquan *et al.* (1988), p. 127. Cf. also (*g*).

[319] As of the mid-1980s, gold washing using traditional methods still accounted for more than 40% of China's total gold production; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 269. The increasing use of dredges, however, is probably now changing this significantly.

[320] Chhen Chih (*1955*), p. 101; cf. also Ma Yun-kho (*1932*), p. 36. [321] Katō (*1926*), p. 729.

[322] *Kai Yü Tshung Khao*, ch. 30; Katō (*1926*), pp. 365–6.

[323] Tylecote (1992), p. 45. Overall, the earth's crust contains only about 0.2% as much native silver as native copper; Gale & Gale (1981) p. 181; Patterson (1971), pp. 296–7. If we compare the amount of the metal appearing as useful nuggets and ignore the uniquely rich native copper deposits of the Lake Superior region, that percentage drops to perhaps 0.15%; Patterson (1971) p. 297, table 6.

[324] Lilley (1936), p. 597. Thao Hung-ching in the +5th century drew on this fact to contrast deposits of silver and gold: 'Silver is found in the same places as gold but silver grows within the earth (*tan shih sheng thu chung yeh* 但是生土中也).' Cited in *PTKM* ch. 8, p. 5. The idea of growth, in turn, was very likely suggested by the fact that native silver found at depth is often in the form of filaments; Shepherd (1980), p. 218. The Chinese pharmacologists regularly distinguished native silver (*sheng yin* 生銀 'raw silver') and vein silver (*shu yin* 熟銀 'processed silver'); *PTKM*, ch. 8, p. 5; de Mély (1896), p. 157.

silver does occur is typically in the form of delicate filaments or thin foil; in contrast to gold, these bits cannot be consolidated by hammering but must be melted together before enough is obtained to make even small objects.[325] Thus, awareness of the very existence of silver, not to speak of an ability to make use of it, could well have come to the Chinese long after they had begun to use gold or copper[326] and native silver, though available in only small amounts, may well have been the sole source of the metal in China at least until the second half of the −1st millennium.

Fortunately, what native silver does occur can frequently if not abundantly be found in the oxidised zones of metallic deposits.[327] This would have been especially important in the early days of mining in China when oxidised deposits were still relatively plentiful. In later periods, some native silver was also obtained from deposits of native gold since, as we noted above (Section (*e*)(1)(iv)), native gold almost always contains a greater or lesser admixture of silver.[328] Such deposits were especially to be found in the eastern, coastal regions of China (Map 9).[329]

Silver had one characteristic much prized by craftsmen that made useful even small quantities of the metal. While silver is not as malleable as gold or tin and requires annealing after repeated hammering, it is extremely ductile, so that one gram of pure silver can be drawn out to produce more than a mile of fine wire.[330] This encouraged the use of even small amounts of silver as decorative inlay not only on bronze vessels but also on chariots and other objects of wood and lacquer.[331]

It was only when the Chinese learned to mine and process underground argentiferous sulphide ores that significantly larger amounts of silver became available.[332] This advance occurred during the Warring States period at the earliest, and perhaps not until the Western Han.[333] In all likelihood, the Chinese turned first to the lead sulphide, galena. Virtually all galena contains at least small amounts of the silver sulphide, argentite.[334] To extract silver from mixed sulphide ores, the Chinese

[325] Gowland (1912), p. 28; Aitchison (1960), p. 45.

[326] Just possibly, some Chinese may have had their attention drawn relatively early to small amounts of native silver (*yin hsing* 銀星 'silver stars') that can be found in association with native copper in some parts of China. Cf. Hsia Hsiang-jung *et al.* (*1980*), pp. 244–5; Bain (1933), p. 163.

[327] Phan Chung-hsiang (*1951*), p. 142.

[328] This may be reflected in the term *pai chin* 白金 has been used in China to indicate silver and which may be translated either as 'white metal' or 'white gold'. Interestingly, the ancient Egyptian name for silver can also mean white gold; Aitchison (1960), p. 45.

[329] Chu Shou-khang & Chang Po-yin (*1989*), p. 65. The ratio of silver to gold in deposits at Lung-chhüan was typically around 3:7.

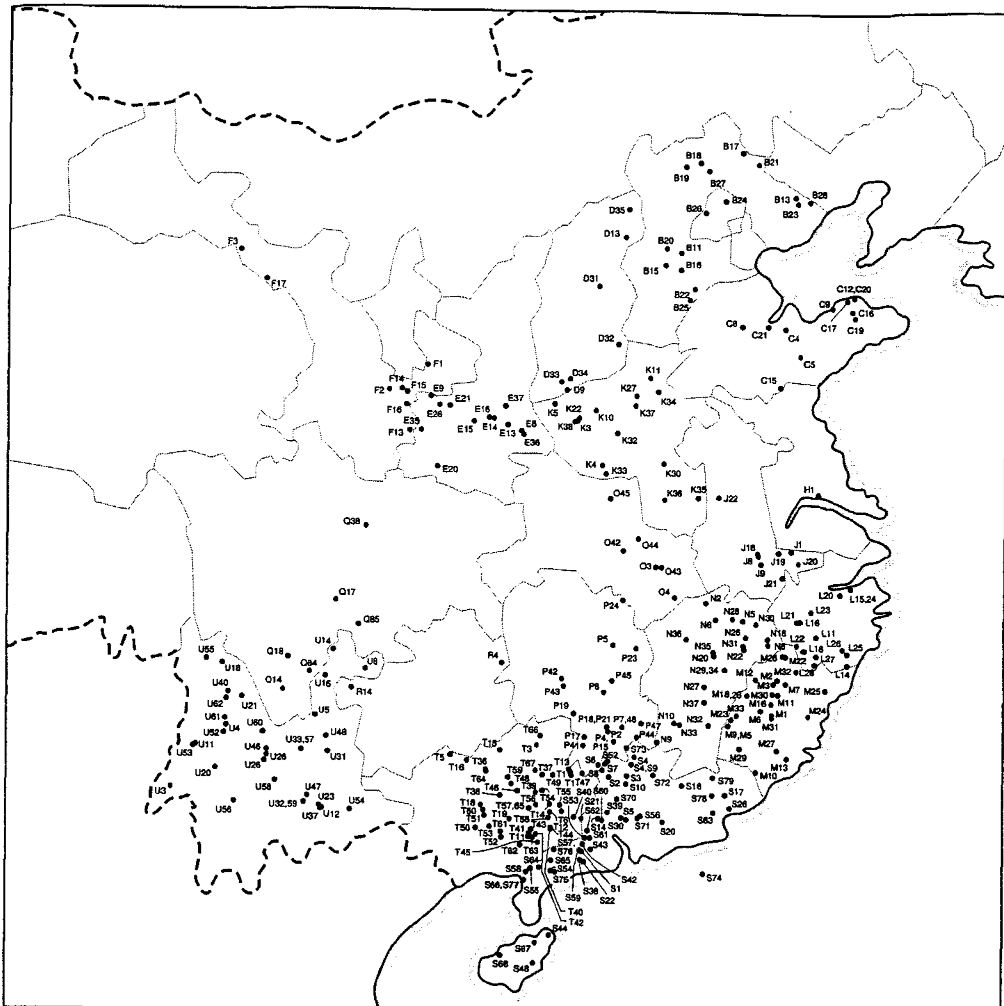
[330] Wheeler & Maddin (1980), p. 105; Jones (1955), p. 172; Ho Yueh-chiao & Chu Fu-hsi (*1986*), p. 146. Because of its lesser malleability, silver was not as suitable for use as leaf, though it was so used on occasion. Hodges (1964), p. 96; Cheng Te-khun (1963), p. 195. Also, it tended to blacken over time. (I am indebted to the Denver goldsmith, Richard Kimball, for pointing this out to me.) Probably for the same reason, tinning was preferred to silvering when a silvery colour was desired on bronzes; Bunker (1994), pp. 75–6.

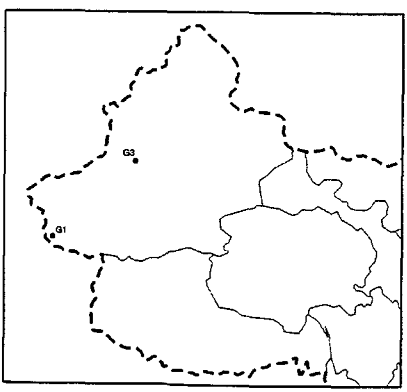
[331] Fong, Wen (1980), p. 376; Cheng Te-khun (1963), p. 88. For the beginnings of gold, silver and copper inlay work in China, see Bunker (1993) p. 34 and the references cited there.

[332] Although there are some 55 well-known silver minerals, most of the world's silver occurs associated in sulphide deposits with the base metals lead, zinc and copper.

[333] Barnard & Satō (1975), p. 100; Bain (1933) p. 162. Silver is not mentioned in surviving pre-Warring States texts and few silver objects survive even from the Warring States period; Barnard & Satō (1975), pp. 69–70; 100.

[334] I Ping (*1972*), p. 40; Aitchison (1960), p. 45. This close association of lead and silver appears frequently in early sources where the same mountain, for example, is said to produce silver and lead; see for example Thien Chhang-hu (*1987*), p. 278. We can safely assume that the vast majority of these cases refer to the obtaining of silver from galena.





Map 9. Pre-20th century silver mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A Liaoning	H Kiangsu	P Hunan
B Hopeh	J Anhwei	Q Szechwan
C Shantung	K Honan	R Kweichow
D Shansi	L Chekiang	S Kwangtung
E Shensi	M Fukien	T Kwangsi
F Kansu	N Kiangsi	U Yunnan
G Sinkiang	O Hupeh	V Kirin

Caption to Map 9. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 9

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
B11	Feng-hsien tung	奉先洞	Shan-chou	檀州					X	
B15	Chen-ting	真定	Cheng-ting	正定					X	
B16	Pao-ting	保定							X	
B17	Feng shan	豐山	Chi-chou	薊州					X	
B18	Yun-chou	雲州	Chhih-chheng	赤城					X	
B19	Wang-yun	望雲							X	
B20	Chü-yang shan	聚陽山							X	
B21	Hui-chou	惠州	Phing-chhüan	平泉					X	
B22	Chi-chen	薊鎮							X	
B23	Yung-phing	永平	Lu-lung	盧龍					X	
B24	Ta-tu	大都	Pei-ching shih	北京市					X	
B25	Lai-shui	淶水							X	
B26	Fang-shan	房山							X	
B27	Yen-chhing	延慶								X
B13	Chhien-an	遷安								X
B28	Fu-ning	撫寧								X
C19	Chhang-yang	昌陽					X			
C20	Pheng-lai	蓬萊					X			
C15	Lin-i	臨沂					X			X
C12	Teng-chou	登州						X		
C9	Lai-chou	萊州						X		
C21	Pan-yang	般陽	Tzu-chhuan	淄川					X	
C8	Chi-nan Ning hai	濟南寧海	Mou-phing	牟平					X	
C15	I-chou	沂州	Lin-i	臨沂					X	
C17	Chao-yuan	招遠								X
C16	Lai-yang	萊陽								X
C4	Lin-chhü	臨朐								X
C5	Chü-chou	莒州								X
D31	Shao-yang shan	少陽山	Chiao-chheng	交城	X		X			
D32	Lu-thai shan	鹿台山	Chang-tzu	長子	X					
D33	An-i	安邑					X			
D9	Phing-lu	平陸					X			X
D13	Wu-thai	五台					X			X
D34	Hsia-hsien	夏縣							X	
D35	Ying-chou	應州								X
E26	Shu-li shan	數歷山	Chhien-yang	千陽	X					
E16	Chhang-an	長安				X			X	
E35	Liang-chhüan	梁泉					X			
E35	Feng-chou	鳳州						X		

Key to Map 9 (*cont.*).

	Sites		Further identification		P1	P2	P3	P4	P5	P6
					Mining Periods					
E9	Lung-chou	隴州						X		
E20	Hsing-yuan	興元	Han-chung	漢中				X		
E8	Shang-chou	商州						X	X	
E21	Feng-hsiang fu	鳳翔府						X		
E36	Feng-huang shan	鳳凰山	Shang-hsien	商縣					X	
E13	Lan-thien	藍田							X	
E14	Hsien-ning	咸寧							X	
E15	Chou-chih	周至							X	
E37	Lin-tung	臨潼								X
F3	Huai-chiang shan	槐江山	Chang-yeh	張掖	X					
F1	Phing-liang	平涼					X			
F13	Liang-tang	兩當					X			
F2	Chheng-chi	成紀					X			
F14	Lung-chheng	隴成	Thai-an	泰安			X			
F15	Chhing-shui	清水					X			
F16	Tai-chou	秦州	Thien-shui	天水				X	X	
F17	Ta huang shan	大黃山	Shan-tan	山丹					X	
G1	Nan-erh	難兒				X				
G3	Khuei-tzu	龜茲				X				
H1	Chiang-tu	江都					X			
J19	Nan-ling	南陵					X			
J20	Ning-kuo	寧國					X		X	
J21	Chi-hsi	績溪					X			
J8	Chhiu-phu	秋浦					X			
J9	Chhing-yang	青陽					X			
J1	Hsuan-chheng	宣城					X			
J22	Pao tzu ya	豹子崖	Huo-chhiu hsien	霍邱縣					X	
J18	Chhih-chou	池州	Kuei-chhih	貴池					X	
K10	I-yang	伊陽					X			
K32	Lu-shan	魯山					X			
K4	Nan-yang	南陽					X			
K5	Kuo-chou	虢州						X		
K10	Hsi-ching	西京	I-yang hsien	伊陽縣				X		
K33	Hu-yang hsien	湖陽縣	Thang-chou	唐州				X		
K27	Cheng-chou	鄭州						X		
K11	Kung-chheng hsien	共城縣	Wei-chou	衛州				X		
K34	Pien-ching	汴京	Khai-feng	開封					X	
K35	An-feng	安豐	Shou-hsien	壽縣					X	
K30	Ju-ning	汝寧	Ju-nan	汝南					X	
K36	Lo-shan hsien	羅山縣							X	
K37	Chao-pao shan	趙寶山	I-yang	宜陽					X	
K22	Yung-ning	永寧	Lo-ning	洛寧					X	
K38	Lu-shih kao tsui erh	盧氏高嘴兒							X	
K3	Ma-shao shan	馬槽山	Sung-hsien	嵩縣					X	
L20	Chu-chi	諸暨					X			
L21	Hsi-an	西安	Chhü-hsien	衢縣			X			
L22	Sung-yang	松陽					X			
L23	Chien-te	建德					X			
L24	Yueh-chou	越州						X		

Key to Map 9 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
L16	Chhü-chou	衢州						X		
L11	Chhu-chou	處州						X	X	
L11	Sui-chhang hsien	遂昌縣	Chhu-chou	處州				X		
L25	Wen-chou	溫州							X	
L11	Li-shui Yen chhüan shan	麗水岩泉山	Chhu-chou	處州					X	
L14	Phing-yang	平陽							X	
L26	Chhing-thien	青田							X	
L27	Ching-ning	景寧	Ho-hsi chen	鶴溪鎮					X	
L28	Thai-shun	泰順							X	
L15	Shao-hsing	紹興								X
L18	Lung-chhüan	龍泉								X
M1	Yu-hsi	尤溪					X			
M7	Chien-an	建安					X			
M18	Chiang-le	將樂					X		X	
M23	Ning-hua	寧化					X		X	
M5	Chhang-thing	長汀					X			
M2	Chien-chou	建州						X		
M24	Fu-chou	福州						X		
M9	Thing-chou	汀州						X		
M10	Chang-chou	漳州						X		
M11	Nan-chien chou	南劍州						X		
M12	Shao-wu chün	邵武軍						X		
M13	Chhüan-chou	泉州						X		
M25	Fu-chou chhang hsi	福州長溪	Hsia-phu	霞浦				X		
M26	Phu chheng	浦城	Chien-chou	建州				X		
M2	Chien-an	建安	Chien-ou	建甌				X		
M3	Chien-yang hsien	建陽縣						X		
M27	Chhüan-chou Chhing hsi hsien	泉州清溪縣	An-hsi	安溪				X		
M28	Chiang le	將樂	Nan-chien chou	南劍州				X		
M10	Lung-hsi hsien	龍溪縣						X		
M29	Lung-yen hsien	龍岩縣	Chang-chou	漳州				X		
M2	Chien-ning	建寧							X	
M30	Yen-phing	延平							X	
M16	Nan-chien	南劍	Nan-phing	南平					X	
M31	Yin-phing shan	銀屏山	Yu-hsi	尤溪					X	
M22	Ma-an shan	馬鞍山	Phu-chheng	浦城					X	
M32	Cheng-ho	政和							X	
M33	Sung-hsi	松溪							X	
M6	Sha-hsien	沙縣							X	
N2	Tzu-sang shan	紫桑山	Chiu-chiang	九江	X					
N2	Hsun-yang	潯陽					X			
N5	Le-phing	樂平					X			
N26	I-yang	弋陽					X			
N27	Yü-shan	玉山					X			
N20	Lin-chhuan	臨川					X			
N6	Pho-yang	鄱陽					X			
N8	Shang-jao	上饒	Hsin-chou	信州			X	X		
N28	Jao-chou	饒州						X		
N22	Hsin-chou	信州						X		
N10	Chhien-chou	虔州						X		
N29	Chien-chhang chün	建昌軍	Nan-chheng	南城				X		
N9	Nan-an chün	南安軍	Ta-yü	大庾				X		
N30	Te-hsing hsien	德興縣	Jao-chou	饒州				X		

Key to Map 9 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
N31	Kuei-hsi	貴溪						X		
N11	Chhien-shan hsien	鉛山縣						X		
N32	Jui chin hsien	瑞金縣	Chhien-chou	虔州				X		
N33	Kan-hsien	贛縣						X		
N34	Nan-chheng hsien	南城縣	Chien-chhang chün	建昌軍				X		
N35	Fu-chou	撫州							X	
N36	Meng shan	蒙山	Jui-chou	瑞州					X	
N37	An-fu	安福							X	
O3	Wu-chhang	武昌					X			
O42	Yung-hsing	永興					X			
O43	O-chou	鄂州						X		
O4	Hsing-kuo	興國	Yang-hsin	陽新					X	
O44	Te-an	德安	An-lu	安陸					X	
O45	Tsao-yang	棗陽								X
P24	Tung-thing shan	洞庭山	Yueh-yang	岳陽	X					
P41	Yung-ming	永明					X			
P4	I-chang	義章					X			
P42	Shao-chou	邵州					X	X		
P2	Phing-yang	平陽					X			
P43	Shao-yang	邵陽					X			
P44	Kuei-yang	桂陽						X		
P17	Tao-chou	道州						X		
P7	Chhen-chou	郴州						X	X	
P8	Heng-chou	衡州						X		
P18	Kui-yang chien	桂陽監						X		
P5	Than-chou	潭州						X		
P45	Heng-shan	衡山						X		
P23	Liu-yang hsien	瀏陽縣						X		
P19	Yung-chou	永州	Ling-ling	零陵				X		
P21	Kui-yang chou	桂陽州							X	
P46	Chhen-chou	辰州							X	
P15	I-chang	宜章							X	
P47	Hsing-ning	興寧								X
Q84	Chu-thi	朱提	I-pao	宜寶		X	X			
Q38	Pa-hsi	巴西					X			
Q14	Hui-li mi le shan	會理密勒山							X	
Q18	Chien-chhang	建昌	Hsi-chhang	西昌					X	
Q85	Hsu-chou fu	敘州府	I-pin	宜賓					X	
Q17	Le-shan	樂山								X
R4	Thung-jen	銅仁							X	
R14	Hsien-ning	咸寧								X
S9	Chhü-chiang	曲江					X		X	
S21	Khang-chou	康州	Te-chhing	德慶			X	X		
S38	Yang-chiang	陽江					X			
S7	Kuei-yang	桂陽					X			
S26	Hai-yang	海陽					X			
S40	Tuan-hsi	端溪					X			
S52	Lung-shui	瀧水					X			
S53	Feng-chhuan	封川					X			
S54	Mao-ming	茂名					X			

Key to Map 9 (*cont.*).

	Sites		Further identification		P1	P2	P3	P4	P5	P6
S1	Yang-chhun	陽春					X			
S42	Thung-ling	銅陵					X			
S55	Lien-chiang	廉江					X			
S56	Shih-lung	石龍					X			
S43	En-phing	恩平					X			
S44	She-chheng	舍城					X			
S57	Hsin-i	信義					X			
S58	Wu-lei	烏雷					X			
S4	Shao-chou	韶州						X		
S5	Kuang-chou	廣州						X		
S3	Ying-chou	英州						X		
S6	Lien-chou	連州	Lian-hsien	連縣				X	X	
S38	En-chou	恩州	Yang-chiang	陽江			X	X		
S59	Chhun-chou	春州						X		
S18	Hsun-chou	循州						X		
S17	Chhao-chou	潮州						X		
S60	Tuan-chou	端州						X		
S22	Nan-en chou	南恩州						X		
S20	Hui-chou	惠州						X		
S61	Hsin-hsing	新興	Hsin-chou	新州			X	X		
S62	Feng-khai	封開	Feng-chou	封州				X		
S63	Mei-chou	梅州						X		
S64	Hua-chou	化州						X	X	
S65	Kao-chou	高州						X		
S66	Lien-chou	廉州	Ho-phu	合浦			X	X		
S67	Chhiung-chou	瓊州	Chhiung-shan	瓊山				X		
S68	Chhang-hua chün	昌化軍	Chhang-chiang	昌江				X		
S48	Wan-an chün	萬安軍	Wan-ning	萬寧			X	X		
S4	Chhü-chiang hsien	曲江縣	Shao-chou	韶州					X	
S30	Fan-yü	番禺					X		X	
S70	Chhing-yuan	清遠							X	
S71	Tung-kuan	東莞							X	
S8	Yang-shan	陽山							X	
S2	Lien-shan	連山							X	
S72	Weng-yuan	翁源							X	
S73	Le-chhang	樂昌							X	
S10	Ying-te	英德							X	
S39	Ssu-hui	四會							X	
S14	Kao-yao	高要					X		X	
S74	Shih-chheng	石城							X	
S75	Tien-pai	電白					X		X	
S76	Hsin-i	信宜							X	
S77	Chhin-chou	欽州							X	
S78	Feng-shun	豐順								X
S79	Mei-hsien	梅縣	Chia-ying chou	嘉應州						X
T36	I-chou	宜州	I-shan	宜山			X	X		
T37	Li-shan	立山					X			
T38	Lai-pin	來賓					X			
T39	Wu-lang	武郎					X			
T40	Phu-ning	普寧					X			
T41	Nan-liu	南流					X			
T42	Lung-hua	龍化					X			
T43	Fu-an	撫安					X			
T44	Tshen-hsi	岑溪					X			

Key to Map 9 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
T45	O-shih	峨石					X			
T46	Yang-shou	陽壽					X			
T12	Than-chin	鐔津					X			
T47	Lung-shui	龍水					X			
T6	Tshang-wu	蒼梧					X			
T1	Lin-ho	臨賀					X			
T48	Ma-phing	馬平					X			
T49	Lung-phing	龍平					X			
T50	Hsuan-hua	宣化					X			
T18	Shang-lin	上林					X			
T51	Ling-fang	領方					X			
T52	Ning-phu	寧浦					X			
T53	Yung-ting	永定					X			
T11	Yü-lin	鬱(林)					X			
T13	Ho-chou	賀州						X		
T54	Chao-chou	昭州	Phing-le	平樂			X	X		
T55	Wu-chou	梧州						X		
T14	Theng-chou	滕州						X		
T15	Jung-chou	融州						X		
T56	Kung-chou	龔州	Phing-nan	平南			X	X		
T57	Hsun-chou	潯州	Kuei-phing	桂平				X		
T58	Kui-chou hsien	貴州縣						X		
T59	Liu-chou	柳州						X		
T60	Pin-chou	賓州						X		
T61	Heng-chou	橫州						X		
T62	Pai-chou	白州	Po-pai	博白			X	X		
T63	Yü-chou	鬱州	Yü-lin	玉林				X		
T64	Chhing-yuan fu	慶遠府	Yi-shan	宜山					X	
T5	Nan-tan	南丹							X	X
T65	Hsun-chou fu	潯州府	Kuei-phing	桂平			X		X	
T56	Phing-nan	平南					X		X	
T19	Kuei-hsien	貴縣							X	
T3	Lin-kuei	臨桂					X			X
T1	Ho-hsien	賀縣								X
T66	Ling-chhuan	靈川								X
T16	Ho-chhih	河池								X
T67	Li-phu	荔浦								X
U31	Lü-kao	律高	Lu-liang	陸良		X				
U32	Pen-ku	賁古	Chien-shui	建水		X				
U26	Shuang-pai	雙柏				X				
U33	Tien	滇	Khun-ming	昆明		X				
U3	Ai-lao	哀牢				X				
U46	Wei-chhu	威楚	Chhu-hsiung	楚雄					X	X
U4	Ta-li	大理							X	X
U11	Chin-chhih	金齒							X	
U47	Lin-an	臨安							X	
U18	Yuan-chiang	元江							X	
U53	Yung-chhang	永昌	Pao-shan	保山					X	X
U5	Tung-chhuan	東川							X	
U48	Chhü-ching	曲靖							X	
U52	Yao-an	姚安							X	
U56	Chen-juan	鎮沅							X	
U26	Nan-an chou	南安州	Shuang-pai	雙柏					X	
U57	Yun-nan	雲南	Khun-ming	昆明						X

Key to Map 9 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
U12	Hui-tse	會澤								X
U14	Yung-shan	永善								X
U16	Lu-tien	魯甸								X
U8	Chen-hsiung	鎮雄								X
U58	Hsin-phing	新平								X
U20	Shun-ning	順寧								X
U40	Li-chiang	麗江								X
U54	Khai-hua	開化	Wen-shan	文山						X
U21	Yung-pei	永北								X
U37	Ko-chiu	個舊								X
U59	Chien-shui	建水								X
U26	Nan-an	南安								X
U60	Ta-yao	大姚								X
U61	Cheng-chhuan (chhen)	鄭川(鎮)								X
U62	Ho-chhing	鶴慶								X
U55	Chung-tien	中甸								X
U23	Meng-tzu	蒙自								X

would have had to rely on cupellation. Cupellation is a process that takes advantage of the chemical fact that certain metals such as lead and copper oxidise readily when heated in an ample supply of air while the noble metals, gold and silver, do not. In the cupellation of an argentiferous lead ore such as galena, the lead oxide (litharge) thus formed could (1) be carried away in the air blast used to raise the temperature of the fire, or (2) be absorbed by a porous substance such as the clay, brick, bone ash, etc. of the crucible (cupel) in which it was heated, or (3) remain as liquid litharge in the cupel, in which case the unoxidised silver floated on top of it.[335] This is a topic that has been discussed previously (cf. especially Vol. 5, pt. 2, pp. 36–43, 55–62) and will come up again in the discussion of non-ferrous metallurgy in Section 36c. At the present state of our knowledge and given the paucity of evidence, we can at best guess that cupellation made a rather late appearance in China some time just before or during the Warring States period (–6th to –3rd centuries).[336]

The question of when cupellation came to be applied on any scale to the separation of gold, silver and copper from other metals or materials is even murkier. To judge by the distribution of artefacts recovered by archaeologists, silver does not appear to have become available in any significant amounts until the Han period.[337] Barnard and Satō would even go so far as to suggest that pre-Han silver in China was imported from beyond her borders and that it was perhaps only as late as the

[335] Hodges (1964), pp. 92–3; Craddock *et al.* (1989), p. 59. Cupellation could even be carried out in an open hearth provided some kind of wall or screen or hood was constructed to retain the fire in the face of the air blast and to condense as much as possible the lethal litharge fumes; Craddock *et al.* (1989), pp. 59–60.

[336] Vol. 5, pt. 2, pp. 39–40; 48–9, fn. e; 55–67; Barnard & Satō (1975), pp. 22, fn. 33; 100. The earliest use of mercury amalgams for goldplating can also be traced to the Warring States period; see below, Section (*e*)(1)(vi). Cupellation seems to have been known in western Asia by about –2000; Tylecote (1992), p. 45.

[337] Compare the two maps 3a and 3b in Barnard & Satō (1975), p. 102.

Han that the Chinese learned and applied the techniques, including cupellation, for obtaining silver from sulphide ores.[338] In any case, we do not begin to have texts clearly describing cupellation in any detail until the Thang (+619 to +906) or Sung (+960 to +1279).[339]

Throughout Chinese history, silver seems to have been relatively scarce compared to gold. The first hint of this phenomenon is a hoard of coins found in 1974 at Fu-kou 扶溝 in Honan; in this hoard, gold coins outnumbered silver coins by more than 20 to 1.[340] Later surviving data suggest that the value of silver was typically much closer to that of gold than has usually been the case in most other parts of the world. There is evidence to suggest that the ratio of silver to gold in the Han was 1:10 or lower.[341] Marco Polo gave a ratio of 1:5 in the late +13th century.[342] At least up to the end of the +17th century, gold was not uncommonly worth only 4–8 times as much as silver.[343] It was only from the late +17th century and the vast influx of silver from Spanish colonial America that Chinese gold/silver ratios entered the 1:14 to 1:16 range.[344]

V. K. Ting and W. H. Wong attribute the scarcity of silver in China to poor deposits.[345] While this is surely part of the explanation, other factors may also have played a rôle, including the possibility that the demand for silver was especially high in China because of silver's important place in commercial transactions from Thang times onward.[346] Moreover, Ting and Wong probably underestimate the peculiar metallurgical problems involved in smelting silver sulphide ores.

From the Three Kingdoms period on, we begin to have bits of data on the quality of available silver ores. They give silver contents of 0.045 per cent to almost 4 per

[338] Barnard & Satō (1975), p. 100. A less radical interpretation would hold that pre-Han silver was obtained both from 'foreign trade' and also from the mining of small amounts of native silver within China.

[339] Vol. 5, pt. 2, pp. 57–61; Huang Sheng-chang (*1982*), p. 27. By this time, the Chinese had discovered that purified ash, because of its high absorbency, was an ideal material for making cupels though the use of clay cupels was apparently still common; compare the second and third translations, Vol. 5, pt. 2, p. 58.

[340] The 18 spade-shaped silver coins have been dated by various scholars anywhere from the −7th or −6th centuries down to the early Han; Anon. (*1980*); Thien Chhang-hu (*1987*), pp. 276–8; Wagner (1993), p. 34 and illustration on p. 35, fig. 1.7; Li Hsueh-chhin (*1984*), pp. 309–10 (translated with illustration differing significantly from the illustration in Wagner in Li Xueqin (1985), pp. 378–9.) Though this find is remarkable in suggesting something of a connection between silver and currency, one hesitates on the basis of these 18 examples and with no other archaeological or textual supporting evidence to postulate that these were indeed circulating silver 'coins', all the more so because, with a length of 14 cm and a blade thickness of about 2 cm, they would have been very heavy 'coins' indeed! Quite possibly they were simply ingots given a coin shape to symbolise their value as a precious metal.

[341] Huang Yü-heng & Ai Ta-chheng (*1989*), p. 34.

[342] Brown (1923), p. 146. Actually, we know from Chinese sources that the gold/silver ratio in the Yuan ranged from an official 1:10 at the capital down to a market rate as low as 1:5 in Yunnan, which was a major producer of gold; Ning Chao (*1962a*), p. 21.

[343] Yang Lien-sheng (1952), pp. 42, 47–8, 67; von Glahn (1996), chap. 4; Atwell (1982), p. 82. As Atwell's table shows, the ratio in the Spanish empire in the late +16th and early +17th centuries was typically 12/13: 1.

[344] Atwell (1982); Hsia Hsiang-jung *et al.* (*1980*), p. 171. Throughout the Ming, silver production lagged far below Sung levels; Chhüan Han-sheng (*1976a*).

[345] Ting Wen-chiang & Weng Wen-hao (*1921*), p. 32.

[346] In the Han, gold seems to have been much more widely used in money-like transactions though silver was already being used as a medium of exchange and was even cast by the government into bar-shaped 'coins' or ingots; Yang Lien-sheng (1952), pp. 42–3. For a recent, encyclopedic, and lavishly illustrated treatment of silver coins and ingots throughout Chinese history, see Thang Kuo-yen *et al.* (*1993*).

cent for ores in various parts of the country.[347] The comparability of these figures is questionable, however. It would appear that lower figures tend to refer to raw ore just as it was mined while some if not all of the higher figures refer to ore that had undergone at least some beneficiation or concentration (see Section (*i*)(1) below). Even the orebodies relatively rich in silver tend in China to be small and patchy.[348] It is nevertheless a striking coincidence that the recovery rate given in the *Wei Shu* 魏書 (History of the [Northern] Wei Dynasty) for silver mined around +514 in the Chhang-an area (Li-shan 驪山, very close to the tomb of the First Emperor of Chhin) works out to almost exactly the same rate (7 *liang* 兩 of silver from 2 *shih* 石 of ore or about 0.18 per cent) as the figure given by Aitchison and Bromehead for the average silver content of Athens' lead/silver mines (Map 10) at Laurion (60 oz per ton or 0.1875 per cent)![349] In any case, analysis of silver ore smelting residues from Hsi-an that date from no later than the Thang show only small amounts of silver, suggesting that, by this time at least, the Chinese were able to smelt silver ores quite effectively.[350]

By the late +8th and early +9th centuries, silver production centred on the mines of Fukien, Chekiang, southern Kiangsi and Hunan was booming.[351] It has been calculated that yearly production in the middle of the +9th century surpassed 350,000 Chinese ounces (*liang* 兩), or something over fourteen short tonnes.[352] Probably for the first time, silver enjoyed wider use than gold in Chinese society.[353] Increased

[347] Hsia Hsiang-jung *et al.* (*1980*), p. 289; Chu Shou-khang & Chang Po-yin (*1989b*), p. 64.

[348] Hsia Hsiang-jung *et al.* (*1980*), p. 189; Bain (1933), pp. 162–3; Read (1912), p. 43; Hoover (1899–1900), p. 329.

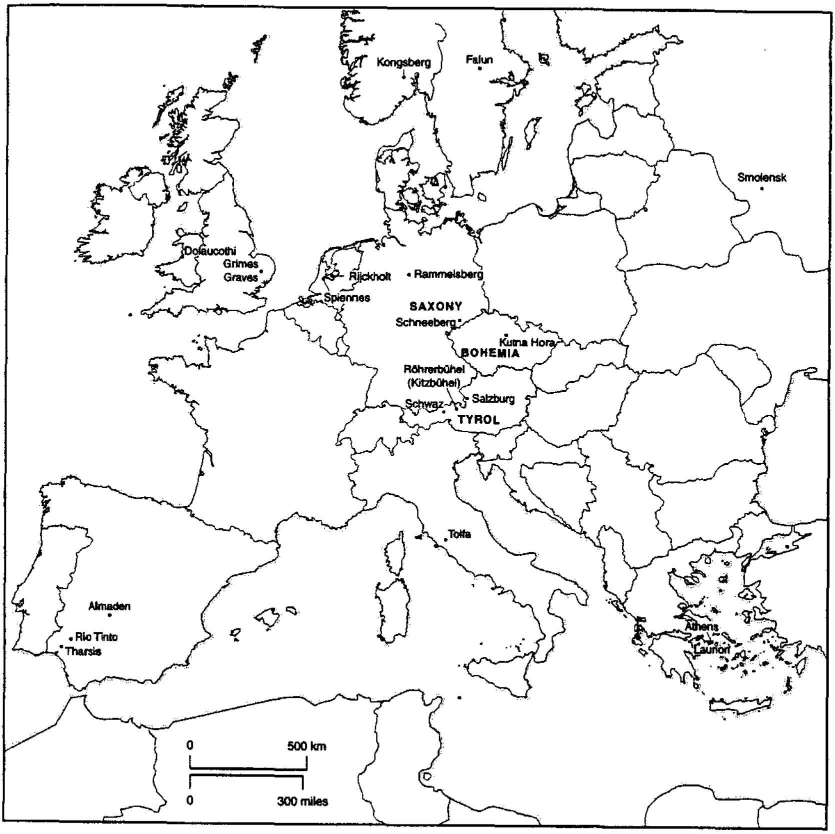
[349] *Wei Shu*, ch. 110, p. 2857; Ma Yun-kho (*1932*), p. 41; Aitchison (1960), p. 148; Bromehead (1940), p. 107. Modern surveys early in this century found the silver content of ores then being mined in China ranging from about 0.03% to 0.08%; Torgasheff (1930), pp. 152–3. It is entirely possible that many richer deposits existed in earlier times but have long since been mined out. A case in point is the deposit at Lung-chhüan 龍泉 in north-eastern Chekiang which was said in the Ming to have a silver content ranging from about 0.07% to about 0.7% (from 3–4 *chhien* 錢 to 2–3 *liang* 兩 for every *luo* 籮 or 25 *chin* 斤 of ore). This text appears in both the *Shu Yuan Tsa Chi*, cited in Hsia Hsiang-jung *et al.* (*1980*), pp. 295–6 (the better version) and in *Lung Chhüan Hsien Chih*, cited in Chang Hung-chao (*1954*), pp. 60–2. It has been translated into Japanese by Yoshida Mitsukuni; Yoshida (*1967*), pp. 240–5.

[350] Hsia Hsiang-jung *et al.* (*1980*), p. 296. An anonymous author in the late 19th century was struck by the ability of silver producers in Mongolia to obtain pure silver 'with the simplest possible appliances.' Anon. (1888), p. 194.

[351] Katō (*1926*), pp. 503–9; Twitchett (1968), p. 76; Huang Sheng-chang (*1982*), p. 27.

[352] Chu Shou-khang & Chang Po-yin (*1989b*), p. 66; Elvin (1973), p. 208. A maximum yearly production of somewhere between 10 and 15 tonnes seems to have prevailed for the next 500 years. Hsia Hsiang-jung *et al.* (*1980*), pp. 106 and 131(12+ tonnes in 1328); Eberstein (1974), pp. 62–3. These data make it clear that the figures given by William of Rubruck, based on his trip to Mongol China in +1253, that can be interpreted to suggest a yearly production of over 1,200 tonnes (Weisgerber (1986), p. 147) are wildly inflated. Rather than ten times the 120 tonnes that Nef (1952, p. 470) estimates as Europe's annual silver production in the first half of the +16th century, China's actual production was only about one-tenth of that figure. China's silver production was also very low when compared with the Athenian mines at Laurion (perhaps 50+ tonnes per year), the Bawdwin mines in Burma in recent centuries (perhaps 50 tonnes per year) and the Potosi mines in Bolivia (175+ tonnes per year between +1574 and +1630); Bronson (1993), p. 82.

[353] Yang Lien-sheng (1952), p. 43; Katō (*1926*), pp. 627–96. The silver boom at the beginning of the +9th century drew large numbers of copper miners into silver mining, creating a shortage of copper for minting coins and leading to efforts by the government to prohibit silver mining; Twitchett (1963), pp. 78–9. The monograph on geography in the *Hsin Thang Shu* mentions approximately 35 silver production sites in the Thang (Katō (*1926*), pp. 503–9; Chu Shou-khang & Chang Po-yin (*1989b*), p. 66), but Yang Yuan, drawing on a wide range of Thang sources, has discovered nearly 100; Yang Yuan (*1982*), pp. 11–33.



Map 10. European mining regions and sites mentioned in the text.

availability of silver may have in part resulted from the Thang miners' greater familiarity with and better control over difficult liquation processes for separating silver from argentiferous copper sulphide ores.[354] In early modern Europe (c. +1450), this discovery was a major stimulus to the development of central Europe's mining and metallurgical industries[355] and Hartwell may be correct to suggest that this discovery in China not only led to greater silver production but also gave a boost to copper

354 Hartwell (1963), p. 8. The apparently first clearly dated textual reference to the process dates from +1061; Vogel (1991c), p. 79. For the metallurgy of the process, cf. Young (1970), p. 90; Vogel (1991c), p. 79; Hoover & Hoover (1912), pp. 491–2, fn. 1 and ff.; and the references in the caption for the illustration of the Chinese process in Vol. 5, pt. 2, pp. 52–3, Fig. 1303.

355 Nef (1952), p. 463. The history of the process in central Europe has received considerable attention recently, especially from Lothar Suhling; see Vogel (1991c), p. 79 and the articles cited there.

mining and smelting since the silver obtained from previously uneconomical or marginal argentiferous copper ores now made them worth working.[356]

Although silver was almost never coined in China, it gradually became important in government finances because it was used to denominate tax assessments, because of actual silver collected in general tax payments, and because of the revenues the government drew from its direct or indirect control over silver mining itself.[357] From the Thang onwards, silver was also a normal medium of exchange in large transactions. By the middle of the +15th century, after the efforts by the early Ming government to revive a paper currency system collapsed, China returned to the basic bimetallic (copper-based coins and silver bullion) monetary system that dated back to the Thang.[358] Strong demand for silver both in the public and private sectors gave silver a purchasing power twice as great as in the Sung and Yuan.[359] Supplemented by imported silver, the metal itself from Japan at first,[360] and then silver coins such as the Mexican dollar, this bimetallic system prevailed in China into the second half of the 19th century.[361] Chinese merchants seem to have developed a strong preference for payments in silver, even over gold. As a Spanish observer of the Chinese merchants in the Philippines at the end of the +16th century noted, they accepted only silver in exchange for their goods 'for they do not like gold, nor any other goods in exchange, nor do they carry any to China.'[362]

(vi) *Zinc*

Extracting metallic zinc from its ores was an especially difficult challenge for traditional metallurgy. Accidental melting of zinc ore in an open fire could never produce metallic zinc, as was the case with lead or tin. Since zinc has a boiling point of 906 °C, it is already a gas at the temperature necessary to reduce its oxide to the

[356] Hartwell (1963), p. 8. By the Northern Sung period, there were well over 60 silver mining sites of some size spread across the entire empire (Anon. (*1978b*), p. 160; Katō (*1926*), pp. 516–26) and Sung production seems to have peaked at 411,420 ounces (Chu Shou-khang & Chang Po-yin (*1989b*), p. 66).

[357] Katō (*1926*), *passim*; Chhüan Han-sheng (*1967*); Eberstein (1974), chap. 4. For rare instances of coinage of silver, cf. Yang Lien-sheng (1952), pp. 45 and 59; Eberstein (1974), p. 102, n. 3. It should be stressed that, despite the ever-growing importance of silver in the Chinese monetary system from Thang times on as well as its increasing importance for the fiscal health of the state apparatus, the government never showed the same concern for silver production as it did for copper. For its limited rôle even in the Chhing, see Vogel (1987a), I.2.

[358] Elvin (1973). pp. 221–2.

[359] Chhüan Han-sheng (*1967*). At least in Yunnan during the Ming, even copper, tin and iron miners often paid their taxes not in the metal they mined but in silver; Ning Chao (*1962a*), p. 15.

[360] The Ming importation of silver from Japan was made possible by 'a minor technological revolution' in Japan in the +16th century that led to the opening of 14 major gold, silver and copper mines between +1540 and +1700; Morris-Suzuki (1994), p. 43.

[361] Eberstein (1974), pp. 76–8; Yang Lien-sheng (1952), pp. 66–70. Although from the +15th century on, silver production in Chekiang and Fukien was significantly supplemented by mines opened in other parts of the empire, especially Yunnan (Eberstein (1974), pp. 79–81), domestic production may well have accounted for little over 10% of all the new silver being added to the economy.

[362] Cited in Atwell (1982), p. 76. This preference for silver may have been due not only to the ubiquity of its use in Chinese commerce but, at least in certain periods, because of differences in the silver/gold exchange rates inside and outside of China; von Glahn (1996), chaps. 4 and 7.

metal (typically, 950–1000 °C).[363] In an open fire or furnace, the vaporised zinc will simply escape into the atmosphere. Even in a closed furnace, unless the vapours are trapped by means of condensation equipment enabling them in the course of cooling to form metallic zinc, they will combine with the carbon dioxide in the furnace and form zinc oxide.[364] Consequently, procedures for producing metallic zinc appeared only quite late in China, as elsewhere in the world.

The inability to produce metallic zinc, however, did not preclude the use of zinc alloys from a very early period. The most famous of these is, of course, the copper/zinc alloy, brass.[365] By means of a cementation reaction during reduction smelting in which gaseous zinc from a copper–zinc ore passed directly into the copper before it could escape or reoxidise, the Chinese actually were able to produce accidental brass with a zinc content of over 20 per cent as early as the Lung-shan 龍山 period (1st half of −2nd millennium).[366] The next step would be the intentional introduction into the smelter charge of a zinc ore such as the carbonate, smithsonite or the hydrated oxide, calamine which would assure the production of brass, though with little control over and therefore great variety in the percentage of zinc in the resulting alloy. We find such variation in zinc content among the six coins from the Wang Mang interregnum (+9 to +23) analysed by Chang Hung-chao, but there is insufficient hard evidence, either textual or in the form of artefacts, to establish that brass was indeed being produced intentionally by this time.[367]

There is, as yet, no firm concensus on when regular production of metallic zinc in any quantity first took place in China.[368] This fascinating but highly complex question will more appropriately be explored in detail in Section 36c. In the meantime, we can briefly summarise what now appears to be the most persuasive view.

Textual evidence can be read to suggest that metallic zinc was known and used by the +10th century.[369] Unfortunately, what seemed to be strong supporting evidence in the form of three zinc-containing coins, two from the very end of the +11th century and one from the very beginning of the +12,[370] turns out not to be very strong after all. In the first place, chemical analysis has shown that two of the coins

[363] Experiment has shown that the lowest possible temperature at which zinc can be reduced from its oxide is 904 °C, just below its boiling point. Murray (1985), pp. 267–8. This ideal is unlikely to have been achieved in primitive smelting efforts, however. See also Yang Wei-tseng & Liu Wen-ming (*1986*).

[364] The problems posed are similar to those involved in the production of mercury, the other volatile metal of antiquity. (Cf. below, Section (*e*)(1)(vii).) Producing metallic zinc was more difficult, however, because it required higher temperatures and the complete exclusion of air; Craddock (1987), p. 189.

[365] For others, cf. Vol. 2, pt. 2, pp. 199–200.

[366] Chao Khuang-hua (*1987*), pp. 324–5; Murray (1985), p. 270. Zinc, along with arsenic and lead, is one of the elements that (1) is 'theoretically reducible under normal conditions of copper smelting' and (2) commonly coexist with copper in naturally occurring ores; Rostoker & Dvorak (1991), p. 5.

[367] Chang Hung-chao (*1923*, *1925*); Chao Khuang-hua (*1987*), p. 324; Murray (1985), esp. p. 270; compare also the slightly different views in Barnard & Satō (1975), pp. 22–3 and Vol. 5, pt. 2, pp. 199ff. Chao's important article highlights the danger of assuming that *huang thung* 黃銅 in pre-Ming texts refers to brass. In the Southern Sung, for example, it was the term regularly used to distinguish copper produced by smelting yellow sulphide ores from that obtained by means of the wet copper process (cf. (*j*) below). It had nothing to do with brass.

[368] For the present state of the controversy as well as discussions of terminology from the Han on that might refer to zinc and brass, cf. Vol. 5, pt. 2, pp. 213ff.; Anon. (*1978b*), pp. 196–200; Chao Khuang-hua *et al.* (*1986*); Zhou Weirong (1993).

[369] Vol. 5, pt. 2, pp. 213–15. [370] Vol. 2, p. 210, Table 98 and p. 213.

have only rather low zinc content of 1.2 per cent and 2.2 per cent respectively. The inadvertent introduction of the zinc from a mixed ore cannot be ruled out here.[371] The third coin, containing 13.1 per cent zinc, would seem to make a stronger case for the intentional introduction of metallic zinc. A recent study by Chao Khuang-hua, Hua Chueh-ming and Chang Hung-li, however, shows this coin to be an anomaly.[372] By means of chemical and spectrographic analysis of 193 Northern Sung coins, they found that the coins produced during all the reign-periods and at all the different mints of the Northern Sung were of generally very high quality and displayed remarkable consistency in their metallic content, averaging 66 per cent copper, 25 per cent lead and 8 per cent tin. *None* of the coins contained more than trace amounts of zinc.[373] Combining these results with some brilliant textual detective work, Chao and his colleagues make a very strong case that metallic zinc was not available in China to any extent before the Ming.[374] The late +14th century to early +15th century may be the period when metallic zinc was first produced in some quantity in China[375] though other scholars including the admirably careful and conservative Chao Khuang-hua would argue for a later date, around the end of the +16th or beginning of the +17th century.[376] Recent work by Chou Wei-jung supports this view.[377] Either date would put the Chinese achievement well before the first production of metallic zinc in Europe (and provide the Chinese with a good export market for zinc in the intervening period). Even the earlier date, however, places the Chinese achievement some three centuries behind developments in India that saw the world's first production of zinc on an industrial scale at Zawar in Rajasthan.[378]

Although lead and zinc are chemically dissimilar, they tend to be produced by the same geological conditions. Thus, the sulphides galena and zincblende as well as their oxidation products (cerussite and anglesite for lead and smithsonite,

[371] Tshao Yuan-yü (*1984*), p. 76.

[372] Chao Khuang-hua *et al.* (*1986*).

[373] *Ibid.*, p. 239. The results were consistent with recent studies by Tai Chih-chhiang and Minakami Shōsei (*Ibid.*, p. 229, fns. 4 and 5). A follow-up study examining 32 Southern Sung coins reveals a clear decline in quality of the coins (seen especially in the presence of greater percentages of ferric impurities) but still only trace amounts of zinc; Chao Khuang-hua *et al.* (*1986a*), esp. pp. 322, table 1 and 326, fig. 2.

[374] Cf. also Chao Khuang-hua (*1987*), p. 329, which argues that the first unmistakable written evidence for the production of metallic zinc in China dates from no earlier than around the beginning of the +16th century. The zinc in the Sung coin may well have resulted from using some brass as a constituent in the minting, all the more so if, as has been suggested, we are dealing with a counterfeit coin; Chao Khuang-hua *et al.* (1986), pp. 244–5; Tshao Yuan-yü (*1984*), p. 76.

[375] Mei Chien-chün (*1990*), p. 22. One result of the availability of metallic zinc was the production of almost pure zinc coins by the very beginning of the +15th century; Vol. 5, pt., 2 p. 213, drawing on Leeds (1955). Nonetheless, it is still possible to argue that most of the Ming brass coins (and all Ming coins after +1527 were made of brass; Bowman *et al.* (1989), p. 27) were still made by smelting metallic copper and smithsonite, not by combining metallic copper and metallic zinc; Chao Khuang-hua (*1987*), p. 330. It is not until Sung Ying-hsing's *TKKW* of +1637 that we get the first reasonably clear account anywhere of zinc metal distillation, though Sung's account is not without its problems of interpretation. *TKKW*, ch. 14, p. 239; Sun & Sun (1966), p. 247; Hu Wen-lung & Han Ju-pin (*1980*); Yang Wei-tseng & Liu Wen-ming (*1986*). (The references in the last include other recent studies of zinc metallurgy in China.)

[376] Chao Khuang-hua (*1987*), p. 330.

[377] Chou Wei-jung (*1996*); Zhou Weirong (1993).

[378] Craddock (1987); Hoover & Hoover (1912), pp. 409–10.

calamine, zincite, willemite and franklinite for zinc) tend the world over to be found together.[379] This holds true also for China.[380]

Unfortunately, apart from scattered references to zinc deposits, there is virtually no information on the mining of zinc ores before the +18th century.[381] About all we know is that, in the early stages of zinc production, the three major centres were Fukien, Han-ku 函谷 in Honan, and Yang-chheng 楊城 in Shansi.[382] By the +18th century, however, all China's major zinc mining was occurring in south central and southwest China, with Kweichow 桂州 clearly the major centre of production and significant mining also occurring in Hunan, Kwangsi and Yunnan (and perhaps also in Szechwan).[383] Many of the deposits were shallow, permitting open-pit mining.[384]

(vii) *Cinnabar and mercury*

The vermilion-coloured sulphide, cinnabar (*tan* 丹, *tan sha* 丹砂, *chu sha* 朱砂; modern term: *chhen sha* 辰砂, deriving from the famous rich deposits at Chhen-chou 辰州 in Hunan), has from early times played a crucial rôle in Chinese mining. Because of its vivid colour, it must have been among the first of the minerals to be clearly identified. Cinnabar also became China's main source of mercury (*kung* 汞, *shui yin* 水銀)[385] and Chinese metallurgists over two millennia put much effort into trying to devise improved methods for extracting mercury from cinnabar.[386] Both the common terms for mercury, one with *shui* 'water' as its radical and the other using *shui* as the first part of the compound, draw attention to the most distinctive characteristic of mercury, that it is the only metallic element that is liquid at normal temperatures.[387]

Cinnabar is found either native (*thu sha* 土砂), usually as crystals (*khuai sha* 塊砂) or powdery depositions (*mo sha* 末砂), or in ore combinations with stibnite, calcite, quartz, bitumen or pyrites (*shih sha* 石砂). The only major centre for cinnabar deposits in China was a 100 km wide belt extending in a southwest-northeast direction some 700 km from northern Yunnan and southeastern Szechwan across Kweichow into western Hunan (Map 11), with deposits that sometimes outcropped at the surface.[388]

[379] Bateman (1950), p. 527. [380] Weng Wen-hao (*1919*), pp. 103ff.

[381] Hsia Hsiang-jung *et al.* (*1980*), p. 186. For figures on zinc production for the government in the +18th century, see Vogel (1987a), IV.1.

[382] *San Yuan Ta Tan Mi Yuan Chen Chih*, cited in Chao Khuang-hua (*1987*), p. 329.

[383] Hsia Hsiang-jung *et al.* (*1980*), pp. 158–9; 186–8. The primacy of this area resulted not only from generally superior deposits in south China but also from the fact that, while zinc predominates over lead in south China deposits, the situation is the reverse in the north, with lead predominating; Wong Wen-hao (1920), pp. 41, 55.

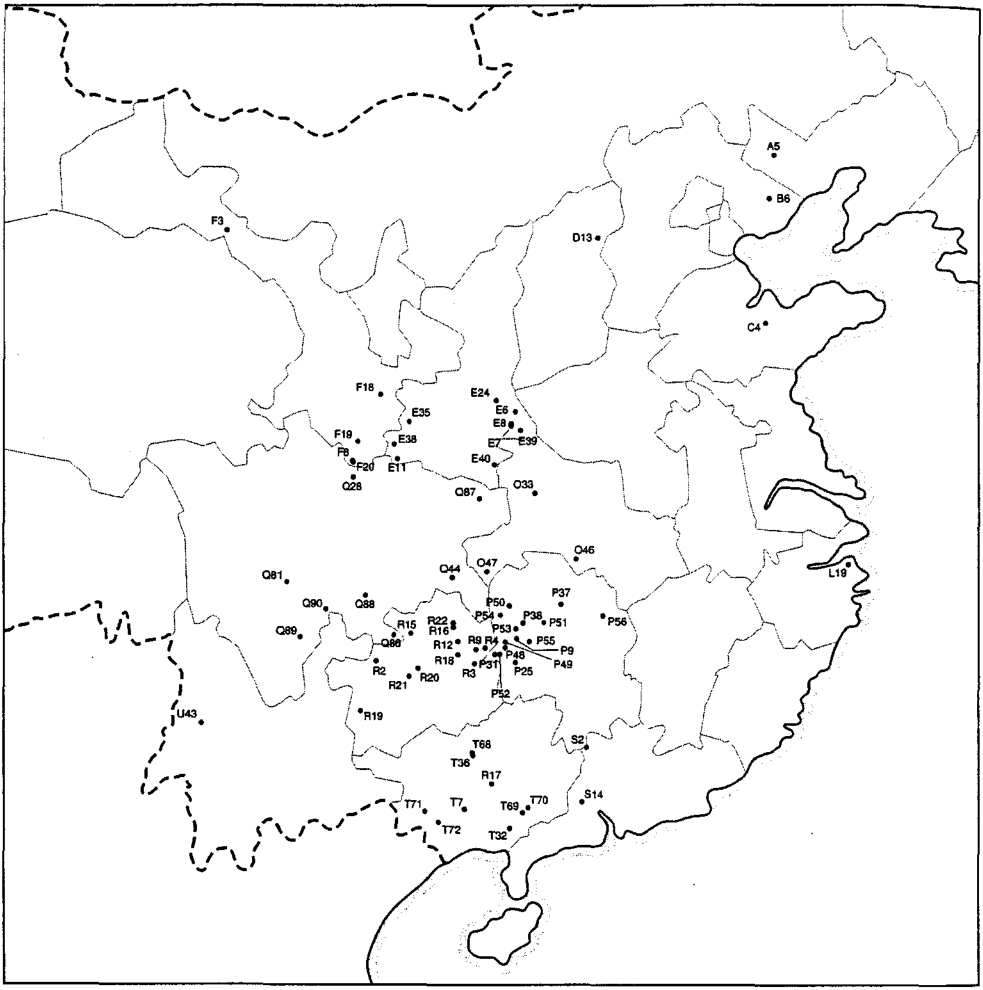
[384] Anon. (1900), p. 456.

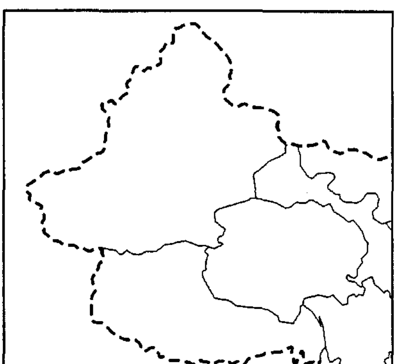
[385] Especially in alchemical works, mercury was sometimes known as 'liquid pearl' (*liu-chu* 流珠); Yoshida (1979), p. 55.

[386] Pure cinnabar can contain up to 86% mercury. Jones (1955), p. 126. There is also a rare black mercuric sulphide, called metacinnabar, which is formed from cinnabar by secondary alteration. Lilley (1936), p. 550. In China, it was found in Hunan and Kweichow and called *wu sha* 烏砂 'black cinnabar'; Hsia Hsiang-jung *et al.* (*1980*), p. 310. The best discussion of methods used by the Chinese to obtain mercury from cinnabar is Chao Khuang-hua (*1984*). For a map of known 'quicksilver' deposits in Kweichow at the beginning of this century, see Tegengren (1920), plate I and pp. 2–3.

[387] For these terms, cf. Vol. 5, pt. 3, pp. 4–5.

[388] Bain (1933), p. 185; Anon. (1891), p. 96. Tegengren has succinctly summarised the main Chinese deposits; Tegengren (1920), p. 4–8, 11–17.





Map 11. Pre-20th century cinnabar/mercury mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A	Liaoning	H	Kiangsu	P	Hunan
B	Hopeh	J	Anhwei	Q	Szechwan
C	Shantung	K	Honan	R	Kweichow
D	Shansi	L	Chekiang	S	Kwangtung
E	Shensi	M	Fukien	T	Kwangsi
F	Kansu	N	Kiangsi	U	Yunnan
G	Sinkiang	O	Hupeh	V	Kirin

Caption to Map 11. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 11

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
A5	Pei-ching	北京	Ling-yuan	凌源					X	
B6	Luan-chou	灤州	Luan-hsien	灤縣					X	
C4	Lin-chhü	臨朐								X
D13	Wu-thai	五台								X
E24	Nan-shan	南山	Wei-nan	渭南	X					
E38	Hsing-chou	興州	Lueh-yang	略陽			X		X	
E8	Shang-chou	商州						X		X
E35	Feng-chou	鳳州						X		
E7	Shang-lo	上洛						X		
E39	Shang-lo	商洛						X		
E6	Lo-nan san hsien	洛南三縣						X		
E11	Ning-chhiang	寧羌							X	
E40	Hsun-yang	洵陽							X	X
F3	Huai-chiang shan	槐江山	Chang-yeh	張掖	X					
F18	Chhin-chou	秦州						X		
F19	Chieh-chou	階州	Wu-tu	武都				X		
F8	Chhü shui	曲水	Wen-chou	文州				X		
F20	Wen-hsien	文縣						X		
L19	Lung-chhüan shan	龍泉山	Yü-yao	餘姚					X	
O46	Ching-chou	荊州			X					
O33	Fang-hsien	房縣								X
O47	Hsien-feng	咸豐								X
P38	Chhen-chou	辰州	Yuan-ling	沅陵			X	X	X	X
P48	Ma-yang	麻陽					X		X	X
P49	Ma-yang	麻陽	Chin-chou	錦州			X			
P50	Yung-shun	永順	Hsi-chou	溪州			X		X	X
P31	Yuan-chou	沅州						X		
P51	An-hua hsien	安化縣	Than-chou	潭州					X	
P52	Wu-chai	五寨	Yuan-chou	沅州					X	
P53	Lu-hsi	盧溪	Lu-hsi	瀘溪					X	X

Key to Map 11 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
P54	Pao-ching	保靖							X	
P9	Chhen-hsi	辰溪								X
P55	Hsu-phu	溆浦								X
P31	Chih-chiang	芷江								X
P25	Chhien-yang	黔陽								X
P56	Phing-chiang	平江								X
P37	Wu-ling	武陵								X
Q81	Fu-ling	涪陵	Pheng-shui	彭水	X	X				
Q86	Hsin-chou	溱州					X			
Q87	Mao-chou	茂州					X			
Q88	Fu-shun chien	富順監						X		
Q44	Pheng-shui	彭水	Chhien-chou	黔州					X	
Q89	Liang-shan	梁山							X	
Q28	Lung-an fu	龍安府	Phing-wu	平武					X	
Q90	Yu-yang	酉陽								X
R15	Than-chih	談指	Thung-tzu	桐梓		X				
R16	Ssu-chou	思州	Te-chiang	德江			X		X	
R17	Wan-shan	萬山							X	
R12	Ssu-nan	思南							X	
R18	Shih-chhien	石阡							X	
R19	Phu-an	普安							X	X
R3	Shih-hsi	施溪	Tshen-kung	岑鞏					X	
R4	Thung-jen	銅仁							X	
R9	Sheng-hsi	省溪							X	
R20	Khai-chou	開州								X
R21	Hsiu-wen	修文								X
R2	Ta-ting	大定								X
R22	Wu-chou	婺州								X
S2	Lien-hsien	連縣	Lien-chou	連州			X		X	X
S14	Kao-yao	高要							X	
T36	I-chou	宜州					X			
T68	I-shan	宜山	Jung-chou	容州			X	X		
T69	Tung shih shan	銅石山	Pei-liu hsien	北流縣					X	
T70	Jung-hsien	容縣							X	
T32	Po-pai	博白							X	
T71	En-chheng	恩城								X
T7	Yung-chou	邕州								X
T72	Kuei-te chou	歸德州								X
U43	Yung-phing	永平								X

The Chinese have probably used cinnabar and mercury more extensively than any other people. The combination of high and consistent demand together with its limited availability assured that there would always be a strong market for good quality cinnabar.[389] In the late Ming, for example, the best quality cinnabar crystals could be worth their weight in silver.[390]

The use of cinnabar as a red pigment probably began very early in China. At least by Shang times, cinnabar was strewn in graves, perhaps to preserve the bodies of the dead[391] or to give the appearance of life (the rosy hue of the skin in northern climes) or to symbolise life (red = blood).[392] Chinese of the Shang also used powdered cinnabar (vermilion) to give a red colour to the incised characters on oracle bones or to make a red ink for writing on the bones. Precious objects of jade and bronze were sometimes wrapped in cinnabar.[393] The *I Chou Shu* 逸周書 (Lost Records of the Chou [Dynasty]) mentions presentation of cinnabar to the Chou king in what would have been the late −11th or early −10th century[394] and cinnabar is mentioned as a tribute item from south-central China in the 'Tribute of Yü' section of the *Shu Ching* (Historical Classic), perhaps drawing on documents or oral traditions going back to the −8th century.[395]

Throughout the centuries, the major use of cinnabar in China was in manufacturing red ink for writing and the red paste used to transfer impressions from the carved seals that took the place of signatures and lent solemnity to documents in China.[396] The process of obtaining vermilion from cinnabar ore through a process of levigation was described by Sung Ying-hsing 宋應星 in the +17th century: 'The ground ore is transferred into a large crock and mixed with water for hydraulic separation. [After settling] for three days and nights, the substance that floats on top of the water is poured off into another crock and called "second-grade vermilion", while the part that sinks to the bottom is dried in the sun and called "first-grade vermilion"' (Fig. 13).[397] Synthesising of cinnabar was accomplished by sublimating

389 The same combination of limited supply and extensive demand was perhaps partly responsible for the Chinese discovery, at least by the +4th century (Tshao Yuan-yü (*1984*), p. 125; Vol. 5, pt. 3, pp. 67–8, 23), that cinnabar could be synthesised by sublimation of mercury with sulphur. The *TKKW* calls the resulting product 'mercury resublimation cinnabar' (*yin fu sheng chu* 銀復升硃); see Fig. 12. Chang Tzu-kao stresses the importance of this discovery for the history of chemistry in China since it was the first time that the Chinese were able to manufacture a substance that was indistinguishable from the naturally occurring variety; Chang Tzu-kao (*1964*), p. 72. Other terms for this 'artificial' cinnabar were 'silver (or mercuric)-red' (*yin chu* 銀朱) or 'divine cinnabar' (*ling sha* 靈砂). This method of manufacturing cinnabar is still commonly referred to in Western technical manuals as the 'Chinese method' (Sun & Sun (1966), p. 288, n. 3) though essentially the same method seems to have been employed in Europe (in the cinnabar mines of Idria, near Venice) as early as the first half of the +16th century; Valentinitsch (1984), p. 201.

390 *Chien Chih Pien*, cited in Tshao Yuan-yü (*1984*), p. 125. 391 Gettens *et al.* (1972), p. 47.

392 Vol. 5, pt. 3, pp. 2–3. This eventually developed into the practice of burying mercury with the dead, presumably to ward off decomposition of the body. Chao Khuang-hua (*1984*, p. 11, fn. 4) notes that Ko Hung (early +4th century) believed that this was a property of mercury. The practice continued at least into the Sung when we hear of emperors regularly honouring meritorious officials by giving them mercury to be included in their tombs; Hsia Hsiang-jung *et al.* (*1980*), p. 111.

393 Vol. 5, pt. 1, pp. 25, 238; Gettens *et al.* (1972), pp. 46, 65; Hsia Hsiang-jung *et al.* (*1980*), pp. 306–7.

394 Vol. 5, pt. 3, p. 3. 395 Legge, (1865), p. 115; see also Vol. 5, pt. 3, p. 4.

396 Tegengren (1920), p. 31; Read (1912), p. 49.

397 *TKKW*, ch. 16, p. 287. Trans. Sun & Sun (1966), p. 280, slightly modified.

Fig. 12. Making vermilion through sublimation of mercury with sulphur. Sun & Sun (1966), p. 283. Compare *TKKW*, ch. 16, p. 293, which uses *sheng* 升 for *sheng* 生.

Fig. 13. Grinding mercury ore and classifying it by levigation. Sun & Sun (1966), p. 281. (Compare with the later version reproduced in Vol. 4, pt. 2, p. 197 which, though artistically more appealing, is rather less precise on certain technical details.)

one part mercury and two parts sulphur in a crock sealed with an iron cover (or in an apparatus made up of two pots sealed together with fireclay) and then recovering the vermilion powder that adhered to the upper part of the inside of the crock (Fig. 12).[398]

Only sulphur could rival the importance of cinnabar and mercury in Chinese alchemy.[399] Cinnabar was also classified among the most efficacious substances used in Chinese medicine and both cinnabar and mercury are frequently to be found in prescriptions for a wide range of ailments.[400]

Besides its extensive use as a pigment, cinnabar also served widely as a polishing agent.[401] In the late Ming, high quality cinnabar for polishing mirrors, arrowheads and other objects was mined at Chhen-chou 辰州 and Chin-chou 錦州 in western Hunan and in western Szechwan respectively.[402] Used for this purpose, the ore was valued in the late Ming at three times what it would have been worth converted into mercury.[403]

Mercury was an important substance in Chinese metallurgy. Mercury forms amalgams with most metals but has a special affinity for gold and silver, with which it combines by a unique wetting process to produce a pasty, silvery pseudoalloy noted for the loud mouselike squeaks it emits when squeezed (Fig. 14).[404] By the Warring States period, liquid or pasty mercury–gold amalgams were widely used for gold-plating metal objects (*liu chin* 鎏金); after the amalgam was applied, the object would be heated, driving off the mercury and leaving the gilding.[405] A similar process was also used for silvering.[406] In recent centuries, at least, mercury has been widely used in China as elsewhere to extract gold and silver from their ores.[407] Mercury was also used for whitening or silvering the surfaces of copper or dark copper-containing alloys.[408] Using it to silver mirrors can be clearly traced back to the time of Thao Hung-ching 陶弘景 (+456 to +536) but the process was probably discovered much earlier, perhaps by the −4th century.[409]

Mercury served as a substitute for water in a number of uses, such as clepsydras (water clocks)[410] or mechanised armillary spheres,[411] to guard against freezing or

398 *TKKW*, ch. 16, p. 288; Sun & Sun (1966), pp. 280, 285. This may have been the first distillation/sublimation process systematically used by the Chinese. If so, it was followed by the distillation of vinegar, and then perhaps distillation of vegetable oils and mineral oils (such as naphtha or Greek fire). Vol. 5, pt. 4, p. 162; Vol. 5, pt. 7, p. 86.

399 Vol. 5, pt. 3, p. 458; pts. 2–4, *passim*.

400 Vol. 3, p. 643; de Mély (1896), pp. 192–6, 198–9. In the −2nd century or earlier work, *Wu Shih Erh Ping Fang* (Fifty-two Prescriptions for Illness), which is the earliest collection of medical prescriptions yet discovered in China, four of the prescriptions, including those for scabies and for burns, make use of mercury; Chao Khuang-hua (*1984*), p. 12.

401 Tegengren (1920), p. 32; Read (1912), p. 49; de Mély (1896), p. 160

402 For a Chinese artist's effort to picture native cinnabar from Chhen-chou, see Vol. 5, pt. 4, Fig. 1522.

403 *TKKW*, ch. 16, p. 287; Sun & Sun (1966), pp. 279–80.

404 Young (1970), pp. 93–4.

405 Lins and Oddy (1975), p. 371.

406 Chao Khuang-hua (*1984*), pp. 11–12; Ho Ping-yü (1968), p. 160; Vol. 5, pt. 2, pp. 246–8; Kho Chün (1987), p. 239. The first clear description of this use is provided by Thao Hung Ching (+456 to +536); Cheng Te-khun (1964), p. 71.

407 Tegengren (1920), pp. 31–2; Verschoyle 1906, p. 919. In the late +16th and early +17th centuries, mercury was a significant export to the Spanish mining centres in the Americas; Atwell (1982), p. 68.

408 Vol. 5, pt. 2, p. 206.

409 *Ibid.*, pp. 247–8; pt. 3, p. 123.

410 Vol. 3, pp. 317; 326–7.

411 *Ibid.*, p. 350.

(a) (b) (c)

Fig. 14. The simplest form of mercury amalgamation, as demonstrated by a miner at Thao-hua 桃花, Kwangsi. (*a*) Mercury is poured into a dish containing gold-bearing sand. The gold is attracted to the mercury. (*b*) After washing off the sand, the miner reaches in and collects the mercury in a small piece of cloth. (*c*) Then most of the mercury is squeezed through the cloth back into the water, and a small amalgam button of gold and mercury remains in the cloth. Original photos, 1994. J. Coggin Brown describes a primitive method for processing the amalgam button to obtain relatively pure gold: 'The amalgam bead is placed in a little hole scraped out of a piece of smouldering cow dung. This is made to glow by being blown on through a narrow tube. The mercury evaporates and leaves a small sphere of gold.' Brown (1923), p. 155.

evaporation. This was also likely to have been the reason for using mercury to depict rivers and the 'great sea' in the map of the world constructed for the tomb of Chhin Shih Huang-ti 秦始皇帝.[412]

Mercury, either as cinnabar or in a chloride form such as calomel, was also one of the many poisonous substances mixed into the gunpowder used in fire-lance or flame-thrower type weapons[413] while cinnabar was a standard ingredient in the recipe for purple military signal smoke.[414]

Finally, mercury was used as the stabiliser in balancing and tumbling toys.[415] This brings to mind that the earliest allusion to mercury among the ancient Greeks was the claim of the comic poet Philippos that a statue of Aphrodite moved in a certain way because the sculptor Daidalos had poured quicksilver into it.[416]

[412] *Ibid.*, p. 582. [413] Vol. 5, pt. 7, pp. 234, 343–4, 489(b). [414] *Ibid.*, pt. 7, p. 144.
[415] Gillan (1974), p. 297. [416] Healy (1978), p. 190.

To my knowledge, no one has emphasised cinnabar's probable rôle as an important stimulus to early mining in China. As noted above, gold and copper are frequently singled out as important for encouraging early mining, in part because they were easy to recognise. Because of its conspicuous bright scarlet colour, however, cinnabar is even more recognisable; it can hardly be missed.[417] Indeed, unless one is dealing with native cinnabar, the very intensity of the colour can be a drawback when prospecting since just a little cinnabar can colour rock to a degree that easily leads to overestimation of the grade of the ore.[418] Early mining of cinnabar was also encouraged by the fact that deposits in China as in many other places often occurred close to the surface. In western Yunnan, southwestern Szechwan and Kwangsi, native cinnabar, which lends itself well to panning because of its heaviness (specific gravity of 8.05), has at least in recent times even been obtained from placer deposits.[419] Very often, however, the richer deposits with the best quality cinnabar occurred at greater depths, and workings at 30, 60 or more metres (*shu shih chang* 數十丈) were common.[420] This was true, for example, of the deposits at Chhen-chou which were famous from Sung times onward for the quality of their cinnabar.[421] Sung Ying-hsing 宋應星 generalised that the best cinnabar was found at depths of about 30 m (one hundred feet).[422] Except for some mining in Shensi, Chinese production of cinnabar has been largely confined to south and especially southwest China. In modern times, most cinnabar has come from Kweichow, neighbouring areas of Szechwan and Hunan, and Kwangsi.[423] Some mining has also been carried on in Kiangsi, Hupeh, Kwangtung, and Yunnan.[424]

We do not know the quality of the ore exploited by the Chinese in early times. What is clear, however, is that rather large cinnabar mines were being worked in south China by the end of the Warring States period (contemporary with the flourishing copper mining at Thung-lü shan 銅綠山). Thus we have the stories of the famous wealthy Widow of Pa 巴 (in present-day eastern Szechwan) whose great wealth came from cinnabar mines[425] and the son of the ruler of Yueh 越 who feared assassination and took refuge in a deep cinnabar mine, only to be forced out by smoke.[426] In recent times, cinnabar mines using native methods sometimes had hundreds

[417] 'Black cinnabar' ore, actually dark opaque red in colour, is also easy to recognise; Brelich (1904), p. 484.

[418] Pearl (1973), p. 340.

[419] Couling (1917), p. 370; Moore-Bennet (1915), 225; Hsia Hsiang-jung *et al.* (*1980*), p. 222. Tegengren (1920, p. 4) notes, however, that placer mining itself, without any other kind of mining, was an indicator that the primary deposits in these areas were poor. For Theophrastus' account of panning cinnabar near Ephesus in ancient times, which stresses varying results depending on the skill of the panner, see Healy (1978), pp. 190–1.

[420] The *PTKM*, ch. 9, p. 51, gives a number of examples, such as Khou Tsung-shih's description in his *Pen Tshao Yen I* (preface dated +1116) of the mining of large cinnabar crystals at the Old Crow Pit (*lao ya ching* 老鴉井) at Chin-chou (錦州) – then under the control of the Liao – which was several hundred feet deep and wide; see (*h*)(6) below.

[421] Tshao Yuan-yü (*1984*), p. 125. [422] *TKKW*, ch. 16, p. 287; Sun & Sun (1966), p. 280.

[423] Tegengren (1920), pp. 1, 7; Weng Wen-hao (*1919*), pp. 201–4; Ting Wen-chiang & Weng Wen-hao (1921), p. 32; Wei Chou-yuan (1946), p. 407. Generally, the mercury content of these deposits is very low, often less than 1% and seldom exceeding 3 or 4%; Tegengren (1920), p. 7.

[424] Chang Hung-chao (*1954*), p. 32; Read & Pak (1928:1936), p. 28. For extensive historical references to major cinnabar and mercury mines in China, see Hsia Hsiang-jung *et al.* (*1980*), pp. 312–17.

[425] Swann (1974), p. 431; Vol. 5, pt. 3, p. 6. [426] *Lü Shih Chhun Chhiu, kuei sheng*, cited by Yen Yü (*1955*), p. 187.

or even thousands of workers. In the 19th century, for example, 2,000 workers at the White Horse Mine (*Pai Ma Tung* 白馬垌) southeast of Tzu-chiang 紫江 hsien in Kweichow were producing approximately 400 tonnes of mercury a year, probably not much under one-half of all the yearly mercury production in China at that time.[427]

Because cinnabar itself was widely used in early times and because mercury seldom leaves archaeological traces,[428] it is very difficult to say when the Chinese first discovered mercury and began to use it. Bits of evidence suggest that the Chinese may have had mercury available in some quantity by the Spring and Autumn period.[429] It was certainly widely available by the end of the Warring States period.[430] The fact that native mercury (*sheng shui yin* 生水銀, *tzu jan kung* 自然汞) is rarely to be found in any substantial amounts (though small deposits occurred in China over a broad area, including Shantung, Hupeh, Hunan, Kwangtung, Szechwan and Kansu),[431] suggests strongly that the Chinese had, by this time, discovered how to derive mercury from cinnabar.[432] The connection between cinnabar and mercury was probably discovered rather easily since small globules of the native metal not infrequently accompany the ore.[433] Moreover, blows from miners' tools can cause cinnabar to shed tears of mercury.[434]

Chao Khuang-hua speculates that the earliest process for obtaining mercury from cinnabar consisted of open-air roasting of cinnabar at a relatively low temperature.[435] Mercury will begin to form at 285 °C and the reaction will be very active by 350 °C, just before the mercury reaches its boiling point (357 °C). Unfortunately, this process has many disadvantages: it is slow, inefficient in terms of the percentage of mercury recovered, and dangerous because of the poisonous fumes.[436]

From at least the Han period,[437] the normal procedure for extracting mercury from cinnabar has incorporated a closed-container, distillation process in which moderate roasting reduces the ore and produces through sublimation a metallic mercury vapour which is then condensed by cooling, and collected.[438] As improvements were made in the process, they presumably broadened the range of ores that could be worked economically, though this is a topic that needs further investigation.

Variations on even the earliest versions of these distillation processes have survived down to the present in China and are still in wide use, especially in the southwest. Though extremely wasteful (Torgasheff estimated early in this century that as much as 40 per cent of the metal was lost because of the crudeness of the distillation

[427] Ting Wen-chiang & Weng Wen-hao (1921), p. 32; Weng Wen-hao (*1919*), p. 203; Wang Hua-lung (*1960*), p. 162.

[428] But see Vol. 5, pt. 3, p. 57.

[429] Chao Khuang-hua (*1984*), p. 11; Hsia Hsiang-jung *et al.* (*1980*), p. 307. The excavation took place in the +3rd century.

[430] Vol. 5, pt. 3, pp. 4–5.

[431] Read & Pak (1928:1936), p. 29; Hsia Hsiang-jung *et al.* (*1980*), pp. 311–12; Chao Khuang-hua (*1984*), p. 14.

[432] Vol. 5, pt. 3, p. 5. [433] Jones (1955), p. 126; Halleux (1974), p. 179. [434] Healy (1978), p. 190.

[435] As in Europe from the +14th or +15th century; Valentinitsch (1984), p. 201.

[436] Chao Khuang-hua (*1984*), pp. 14–15. [437] *Ibid.*, p. 15.

[438] This product was often referred to as *shu shui yin* 熟水銀; Hsia Hsiang-jung *et al.* (*1980*), p. 311.

equipment[439]), these native methods have persisted because they require little capital investment, use readily available materials and fuel, are easy to carry out, and produce the mercury quickly.[440]

(viii) *Nickel*

Nickel was widely used in China in the cupro-nickel alloy 'white bronze' (*pai thung* 白銅) exported in large quantities to the West in the +17th and +18th centuries, where it was commonly known as 'paktong'.[441]

The great centre of cupro-nickel production in China in the late imperial period (and perhaps earlier) was the upper Yangtze border area between Szechwan and Yunnan, where the source of the nickel was mainly the iron–nickel sulphide, pentlandite, which occurred as it does throughout the world associated with chalcopyrite. In the Chhien-lung 乾隆 period of the Chhing, the largest of the four major mining and smelting areas of Hui-li 會理 in Szechwan by itself was producing 37 tonnes of paktong yearly from 216 smelters.[442] Nickel ores can also be found in other areas of China, such as Shensi and elsewhere in Yunnan. Because the use of nickel arsenide is implied in many early texts that speak of adding 'arsenic' to get 'white copper', it seems likely that the Chinese were also mining kupfernickel (the nickel arsenide) and nickel glance (gersdorfite, the nickel arsenic sulphide).[443]

In China, cupro-nickel has been in use since at least the +4th or +5th century[444] for coins, tea and wine pots, plates, incense-burners, candlesticks, and water tobacco-pipes,[445] though the Chinese never moved on to isolate metallic nickel in traditional times.[446]

(2) Iron

In many early cultures, the first iron to be used came from meteorites.[447] This was true also in China, where the earliest artefact so far discovered that incorporates iron – a *yueh* 鉞 battle-axe mostly made of bronze but with an iron blade – dates

[439] Torgasheff (1930), p. 244. Arthur Moore-Bennet, who provides a good description of the furnaces used in Yunnan at the beginning of the 20th century (1915, p. 225), even claimed that 'fully one half the mercury is lost in the process.' Brelich (1904), p. 49) says 30 to 40% for the mercury mines of Kweichow.

[440] Chao Khuang-hua (*1984*), p. 20.

[441] For nickel in China, cf. Vol. 5, pt. 2, pp. 225–42 and Mei Chien-chün & Kho Chün (*1989*), which together provide a good entrée to the earlier literature. The latter also assembles surviving Ming and Chhing references.

[442] Vol. 5, pt. 2, p. 232, fn. (a); Mei Chien-chün & Kho Chün (*1989*), p. 65; Bateman (1950), p. 587.

[443] Vol. 5, pt. 2, p. 232, fn. (a); Needham (1976), p. 284. Recent experiments by members of the Archaeometallurgy Group of the University of Science and Technology Beijing suggest that some of the nickel came from nickelliferous pyrrhotite containing 1–3% nickel.

[444] Mei Chien-chün & Kho Chün (*1989*), pp. 67–8; possible evidence for earlier use is given in Vol. 5, pt. 2, pp. 232–3.

[445] *Ibid.*, pp. 231; 232, fn. (a); Pl. CDL, Fig. 1324.

[446] Needham (1976), p. 284; Read (1912), p. 45.

[447] Rickard (1932), p. 147; Coghlan (1956), pp. 29–31; Tylecote (1992), p. 3; Rostoker & Bronson (1990), p. 42. On the complex question of determining whether an iron artefact was made from meteoritic iron, see Rostoker & Bronson (1990), appendix C, pp. 201–3.

from about the −15th century.[448] But whether this or other meteoritic iron artefacts were actually made in any part of the area that is now China and can therefore indicate some ability of the Chinese by the second half of the −2nd millennium to recognise and work iron is very much open to question. Noel Barnard, whose familiarity with the range of early metallic artefacts unearthed in China is perhaps unsurpassed, argues forcefully that it is 'beyond a reasonable doubt' that these artefacts 'could not have been fabricated by Chinese artisans with the knowledge and technical facilities at their command.' His conclusion is that such articles came to China 'as the result of occasional contacts with nomadic peoples far to the west and beyond the present boundaries of China'.[449]

Whether or not the Chinese themselves ever made use of the small amounts of meteoritic iron available to them to fabricate artefacts,[450] the experience would have been of little help in leading them to discover terrestrial sources of iron since exploitable deposits of native iron are extremely rare. Tapping into abundant supplies of iron meant that the Chinese had to learn how to extract iron from its ores. This was by no means an easy discovery, since iron ores in their appearance do not at all resemble metallic iron.[451] In all likelihood, it was only after iron itself had been accidentally produced and recognised that efforts began to identify the ores from which it could be produced.[452] Donald Wagner has carefully assessed the furnaces used for copper smelting at Thung-lü shan 銅綠山 and has concluded that (1) metallic iron could have have been produced accidentally in these furnaces and may indeed have been quite familiar to the copper-smelters as an indicator of improper operation of the furnace; (2) with very minor modifications, such as increasing the amount of charcoal charged and perhaps reducing the blast, these furnaces could have served adequately to produce molten iron instead of copper; (3) given the sophisticated level bronzecasting techniques had reached by this time, it would not have been difficult for the foundrymen to work out techniques for casting iron into useful objects; and (4) efforts to produce molten iron could also have accidentally resulted in some amount of low carbon 'bloom iron' being left behind unmelted in the furnace, which in turn could have been worked by smithy techniques.[453] While Wagner notes that there is no evidence for the smelting of iron at at Thung-lü shan in ancient times,[454] the important point for our purposes is that there existed in the bronzemaking

[448] Li Chung [pseud.] (*1976*); Hua Chueh-ming (*1982*). According to Barnard (1983, p. 248, fn. 11), the site has been 'reliably' radiocarbon-dated to −1498 ±114.

[449] Barnard (1983), p. 248.

[450] In contrast to other forms of iron, meteoritic iron is resistant to atmospheric corrosion; Aitchison (1960), p. 100. Therefore, the fact that so few artefacts of meteoritic iron have been discovered suggests that, if it was used by the early Chinese, it was at most on a very small scale.

[451] Coghlan (1956), p. 13.

[452] Including hematite, a mineral that the Chinese used as a pigment from around −17,000; Hsia Hsiang-jung *et al.* (1980), pp. 9–10.

[453] Wagner (1993), pp. 48–9. This corresponds nicely with the assessment by Barnard & Satō that '[t]he emergence of iron casting in China . . . was simply the outcome of a highly advanced metallurgical industry of a standard unknown elsewhere in antiquity.' Barnard & Satō (1975), p. 61.

[454] Wagner (1993), p. 49. The same point was suggested earlier by Barnard (1989, p. 185): the traces of copper found in iron tools at Thung-lü shan is lower than one would expect had Thung-lü shan ores been used.

industry of 'China' by about −500 at the very latest the basic technology for producing either cast or bloomery iron.[455] It comes then as no great surprise that wrought and cast iron seem to make their appearance at least in south China at approximately the same time, quite possibly in the course of the −6th century or a little earlier.[456] In the present state of our knowledge, it is not possible to say which came first. Indeed, it is not inconceivable that in certain areas the use of wrought iron preceded that of cast iron, while in other areas the reverse was true.[457] Moreover, existing evidence at this time is still consistent with the hypothesis that iron *casting* was an invention that first took place in China.

Once the connection had been made between iron ores and the metal, large and easily worked iron deposits were widely available in China from early times right down to the end of the imperial period (Map 12).[458] The major iron minerals[459] worked were the three oxides – magnetite, hematite and limonite – and one carbonate – siderite (Table 9).[460] In addition, pyrite (iron sulphide) was the major source of sulphur (cf. below, Section (4)(ii)). These minerals appeared in various kinds of ores: ironsand which was often very rich[461]; ore nodules at or close to the surface of the earth (frequently in the form of spongy bog iron[462]; Fig. 17); nodules in underground beds where they might weigh from a few to several hundred kilograms;[463] and massive deposits occurring either as outcrops or underground.

455 Han Rubin *et al.* (1986). p. 12. As of yet, however, it has not been established that bloomery furnaces *per se* were ever used in ancient China; see the discussion in Wagner (1993), pp. 288–94.

456 Wagner (1993), p. 146 (but cf. also von Falkenhausen (1993–1994), esp. pp. 104–5 which emphasises discoveries of early iron objects in north and northwest China that have come to light since Wagner was writing his book and that, because of 'cultural-processual parallels to early iron use in west Asia' (especially the use of iron in what were clearly items of prestige) raise the possibility of the diffusion of wrought iron from the West into China.); Anon. (*1982*), p. 147; Huang Chan-yueh (*1976*), p. 68. For possibly even earlier artefacts, cf. Tsou Hou-pen (*1982*); Chhen Ko & Ku Mei-hsien (*1990*), p. 41.

457 That a spongy 'bloom' could be transformed into wrought iron by hammering it at red-hot heat was such a remarkable discovery that, even today, it is difficult to imagine how it might have been made. This consideration, together with the small rôle of working by hammering in the early Chinese metallurgical tradition (Barnard (1983, p. 251, fn. 18) would say non-existent rôle) reinforces the hypothesis that the production and use of wrought iron was a technology that the Chinese imported from non-Chinese iron-using peoples.

The same hypothesis may also be relevant when assessing a striking discovery recently made during the examination of a bronze vessel from the −12th or −11th century in the Arthur M. Sackler Collections. This revealed the presence of a spacer or chaplet (used in the casting process to maintain a constant space between the core and the mould) made of what seems to be manufactured iron. If this spacer was indeed used in the original casting, as appears to be the case, this would be by about 500 years the earliest evidence for the use of terrestrial iron in China; Meyers (1988), p. 290.

The lack of archaeological evidence seriously undercuts the efforts of some scholars, led by Kuo Mo-jo, to place the earliest Chinese mining and smelting of iron in the Shang dynasty or earlier. Their suggestions rest on a very small body of less-than-explicit texts as well as a certain amount of circumstantial evidence (e.g. existence of easily discovered iron ores in places mentioned in the texts). For a summary of these interpretations, with references, see Hsia Hsiang-jung *et al.* (*1980*), pp. 210ff.

458 For a detailed discussion of China's iron ores as they were known in the early part of this century, see the still indispensable Tegengren (1924). Bronson notes that the savings on labour (and he might have added, tools) because of large, high quality and easily accessible iron deposits made iron production economically attractive compared to, say, copper with its much higher costs of extraction and beneficiation, this despite the typically higher fuel costs required for smelting iron.

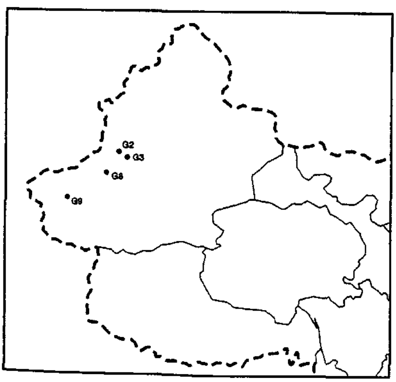
459 For the useful distinction between iron minerals and iron ores, see Rostoker & Bronson (1990), pp. 42–4.

460 We know that the ore used in one of the earliest blast furnaces discovered in China – from about the −1st century, was a rich hematite; Wagner (1985), p. 48.

461 Wagner (1985), p. 12; Wagner (1993), p. 49.

462 For bog iron in China, see Wagner (1993), p. 262.

463 Nyström (1912), p. 51.



Map 12. Pre-20th century iron mining sites in China.

The data on which this map is based has been drawn mainly from Hsia Hsiang-jung *et al.* (*1980*), Yang Yuan (*1982*), and Chang Hung-chao (*1954*). For checking the information, Aoyama (*1933*) and Than Chhi-hsiang *et al.* (1991) have been especially helpful.

Each site is identified by a province code letter and its own number. To facilitate cross-checking, these identifications are consistent for Maps 3, 7, 8, 9, 11 and 12. The code letters for the provinces are as follows:

A	Liaoning	H	Kiangsu	P	Hunan
B	Hopeh	J	Anhwei	Q	Szechwan
C	Shantung	K	Honan	R	Kweichow
D	Shansi	L	Chekiang	S	Kwangtung
E	Shensi	M	Fukien	T	Kwangsi
F	Kansu	N	Kiangsi	U	Yunnan
G	Sinkiang	O	Hupeh	V	Kirin

Caption to Map 12. (*cont.*).

Where useful, further information for purposes of identification has been provided, such as the administrative unit of which a mountain was a part, or the modern name for a place when it differs significantly from the name it bore in earlier times.

For each site, the periods are indicated for which there is evidence for mining of the relevant metal at that site.

P1 Pre-Han (To −202)
P2 Han (−202 to +220)
P3 Period of Division, Sui, Thang (+220 to +906)
P4 Five Dynasties, Sung (+907 to +1279)
P5 Yuan, Ming (+1279 to +1644)
P6 Chhing (+1644 to 1900)

Key to Map 12

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
A8	Phing-kuo	平郭	Kai-hsien	蓋縣		X				
A9	Liao-tung tu su san wan wei	遼東都司三萬衛	Khai-yuan	開原					X	
A10	Liao-yang	遼陽							X	
B29	Han-tan	邯鄲			X					
B30	Wu-an	武安				X				
B31	Tu-hsiang	都鄉	Ching-hsing	井陘		X	X			
B32	Cho-hsien	涿縣				X				
B33	Hsi-yang	夕陽	Luan-hsien	灤縣		X				
B34	Pei-phing	北平	Man-chheng	滿城		X				
B35	Phu-wu	蒲吾	Phing-shan	平山		X	X			
B2	Thang-hsien	唐縣					X			
B36	Lin-shui	臨水	Tzhu-hsien	磁縣			X			
B37	Sha-ho	沙河					X			
B38	Nei-chhiu	內邱					X			
B39	Ma-chheng	馬城	Luan-hsien	灤縣			X			
B40	Yeh	鄴	Lin-chang	臨漳			X			
B41	She-hsien	涉縣					X			
B42	Chao-i	昭義					X			
B22	Chi-hsien	薊縣					X			
B43	Tzhu-chou	磁州						X		
B44	Hsing-chou	邢州						X		
B45	Shun-te	順德	Hsing-thai	邢台					X	
B11	Shan-chou	檀州	Mi-yun	密雲					X	X
B46	Ching-chou	景州	Ching-hsien	景縣					X	
B47	Tsun-hua	遵化							X	
B13	Chhien-an	遷安							X	X
B48	Lu-lung	盧龍							X	X
B49	Ku-pei khou	古北口								X
B50	Hsi-feng khou	喜峰口								X
C22	Shan-tung	山東			X					
C23	Shan-yang	山陽	Chin-hsiang	金鄉		X				
C24	Chhien-chheng	千乘	Po-hsing	博興		X				
C25	Tung-phing ling	東平陵	Chi-nan	濟南		X				
C26	Li-chheng	歷城	Chi-nan	濟南		X	X		X	
C27	Tung-wu	東武	Chu-chheng	諸城		X				
C28	Ying	嬴	Lai-wu	萊蕪		X	X		X	X
C29	Lin-tzu	臨淄				X				X
C30	Tung-mou	東牟	Mou-phing	牟平		X	X			
C31	Yü-chih	郁秩	Phing-tu	平度		X				

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
C5	Chü-hsien	莒縣				X				
C32	Wu-yen	無鹽	Tung-phing	東平		X				
C33	Lu	魯	Chhü-fu	曲阜		X				
C34	Hsia-mi	下密	Wei-hsien	濰縣			X			
C13	Tzu-chhuan	淄川					X			
C16	Chhang-yang	昌陽	Lai-yang	萊陽			X		X	
C12	Teng-chou	登州	Pheng-lai	蓬萊				X	X	
C9	Lai-chou	萊州	Yeh-hsien	掖縣				X	X	
C35	Hsi-hsia	栖霞							X	
C36	Wen-teng	文登							X	
C37	Chi-mo	即墨							X	
C10	I-tu	益都								X
C38	Fu-shan	福山								X
C5	Chü-chou	莒州								X
D36	Pai-ma shan	白馬山	Yang-chhüan	陽泉	X					
D5	Wo-shan	涹山	Lü-liang	呂梁	X					
D33	An-i	安邑	Yun-chheng	運城		X				
D37	Phi-shih	皮氏	Ho-chin	河津		X				
D38	Phing-yang	平陽	Lin-fen	臨汾		X			X	X
D16	Chiang	絳	Hou-ma	侯馬		X				
D39	Ta-ling	大陵	Fen-hsien	汾縣		X				
D40	Yueh-yang	岳陽	An-tse	安澤			X			
D41	Fen-hsi	汾西					X		X	X
D8	I-chheng	翼城					X			
D16	Chiang	絳	Hsin-chiang	新絳			X			
D42	Chi-chhang	吉昌	Chi-hsien	吉縣			X			
D43	Chhang-ning	昌寧	Hsiang-ning	鄉寧			X			
D44	Wen-chhüan	溫泉	Hsiao-yi	孝義			X		X	X
D12	Yü-hsien	盂縣					X			
D20	Chiao-chheng	交城					X		X	X
D45	Mien-shang	綿上	Mi-Yuan	泌源			X			
D46	Hsuan-chhih	玄池	Ching-le	靜樂			X			
D47	Hsiu-jung	秀容	Hsin-hsien	忻縣			X			
D13	Wu-thai	五台					X			
D15	Yang-chheng	陽城					X		X	X
D48	Shao-yi	昭義	Chhang-chih	長治			X			
D49	Ho-hsi	河西					X			
D50	She-hsien	涉縣					X			
D51	Chin-chou	晉州	Lin-fen	臨汾				X		
D52	Wei-sheng chün	威勝軍	Chhin-hsien	沁縣				X		X
D53	Ho-tung	河東	Yung-chi	永濟					X	
D54	Hsi-ching	西京	Ta-thung	大同					X	
D55	Chi-chou	吉州	Chi-hsien	吉縣					X	
D28	Thai-yuan	太原							X	
D56	Tse-chou	澤州	Chin-chheng	晉城					X	
D57	Lu-chou	潞州	Chhang-chih	長治					X	
D15	Chiang-hsien	絳縣					X		X	
D58	Huai-jen	懷仁							X	
D59	Kao-phing	高平							X	X
D60	Hu-kuan	壺關								X
D61	Yü-tzhu	榆次								X
D62	Phing-ting	平定								X
D63	Ting-hsiang	定襄								X

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
E24	Fu-yü shan	符禺山	Wei-nan	渭南	X					
E24	Ying-shan	英山	Wei-nan	渭南	X					
E24	Chu-shan	竹山	Wei-nan	渭南	X					
E25	Chhin-mao shan	秦冒山	Fu-shih	膚施	X					
E27	Lung-shou shan	龍首山	Hsi-an	西安	X					
E21	Chhi-shan	岐山	Feng-hsiang	鳳翔	X					
E13	Yü-shan	玉山	Lan-thien	藍田	X	X			X	
E41	Cheng	鄭	Wei-nan	渭南		X				
E42	Hsia-yang	夏陽	Han-chheng	韓城		X	X			
E21	Yung	雍	Feng-hsiang	鳳翔		X				
E43	Chhi	漆	Pin-hsien	邠縣		X				
E44	Hsia-yang	夏陽	Mien-hsien	勉縣		X				
E45	Mei-yang	美陽	Wu-kung	武功		X				
E6	Lo-nan	洛南					X			
E9	Chhien-yuan	汧源	Lung-hsien	隴縣			X			
E46	Chung-pu	中部	Huang-ling	黃陵			X			
E47	I-chün	宜君					X			
E48	Ho-chhih	河池	Chhao-i	朝邑			X			
E49	Hsi	西	Mien-hsien	勉縣			X			
E35	Liang-chhüan	梁泉	Feng-hsien	鳳縣			X			
E38	Shun-cheng	順政	Lueh-yang	略陽			X			
E38	Chhang-chü	長舉	Lueh-yang	略陽			X			
E50	Hsin-phing	新平					X			
E21	Feng-hsiang	鳳翔						X		
E22	Thung	同	Ta-li	大荔				X		
E35	Feng-chou	鳳州						X		
E51	Yao-chou	耀州						X		
E52	Fang-chou	坊州	Huang-ling	黃陵				X		
E21	Feng-hsiang fu	鳳翔府						X		
E38	Hsing-chou	興州	Lueh-yang	略陽				X		
E53	Hsing-yuan	興元	Nan-cheng	南鄭					X	
E14	Hsien-ning	咸寧							X	
E15	Chou-chih	周至							X	
E16	Chhang-an	長安							X	
E54	Chheng-ku	城固							X	
E55	Ching-yang	涇陽								X
E20	Han-chung	漢中								X
E8	Shang-chou	商州								X
F21	Lung-hsi	隴西	Lin-yao	臨洮		X				
F22	I-chü	弋居	Ning-hsien	寧縣		X				
F1	Phing-liang	平涼					X			
F2	Chheng-chi	成紀	Thai-an	泰安			X			
F23	I-chou	儀州	Hua-thing	華亭				X		X
F24	Kung-chhang	鞏昌	Lung-hsi	隴西					X	
F25	Ning-yuan	寧遠	Wu-shan	武山					X	
F26	An-hua	安化								X
F27	Wei-hsien	徽縣								X
G8	Jo-chhiang nan erh	渃羌難兒	Yeh-erh chhiang	葉爾羌		X				
G9	Sha-tung	莎東				X				
G2	Ku-mo	姑墨	Pai-chheng	拜城		X				
G3	Kuei-tzu	龜茲	Khu-chhe	庫車		X				
H17	Hsia-phi	下邳	Su-chhien	宿遷		X				
H12	Chhü	朐	Tung-hai	東海		X				

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
H13	Lin-tu	鹽瀆	Yen-chheng	鹽城		X				
H2	Thang-i	堂邑	Liu-ho	六合		X	X			
H14	Phei-hsien	沛縣				X				
H15	Pheng-chheng	彭城	Hsu-chou	徐州		X	X	X		
H9	Kuang-ling	廣陵	Yang-chou	揚州		X				
H8	Shang-yuan	上元	Nan-ching	南京			X			
H5	Li-yang	溧陽					X			
H16	Hsu-chou	徐州	Pheng-chheng	彭城					X	
J23	Wan	皖	An-chhing	安慶		X				
J6	Tang-thu	當塗					X			
J19	Nan-ling	南陵					X			
J24	Huai-ning	懷寧					X			
J8	Chhiu-phu	秋浦					X			
J25	Ying-chou	穎州	Fu-yang	阜陽					X	
J17	Hui-chou	徽州	Hsi-hsien	歙縣					X	
J20	Ning-kuo	寧國	Hsuan-chheng	宣城					X	
J13	Thung-ling	銅陵							X	
K25	Tho-shan	橐山	Shan-hsien	陝縣	X					
K25	Kuo-shan	虢山	Shan-hsien	陝縣	X					
K27	I-shan	役山	Cheng-chou	鄭州	X					
K39	Shao-shih shan	少室山	Sung-shan	嵩山	X					
K40	Mi-hsien	密縣			X	X				
K24	Mi-shan	密山	Hsin-an	新安	X				X	
K34	Ta-liang	大梁	Khai-feng	開封	X					
K4	Wan	宛	Nan-yang	南陽	X	X			X	
K41	Sheng-chhih	澠池				X				
K42	Lung-lü	隆慮	Lin-hsien	林縣		X				
K23	Lo-yang	洛陽				X				
K43	Yang-chheng	陽城	Teng-feng	登封		X			X	
K44	Hsi-phing	西平				X				
K21	I-yang	宜陽				X			X	
K31	Thieh sheng kou	鐵生溝	Kung-hsien	鞏縣		X				
K45	Chu-yang	朱陽	Ling-pao	靈寶			X			
K46	Wu-yang	舞陽					X			
K47	Lin-lü	林 LU:	Lin-hsien	林縣			X			
K48	Yeh-hsien	鄴縣					X			
K49	Hsiang-chou	相州	An-yang	安陽				X		
K23	Ho-nan	河南	Lo-yang	洛陽				X		
K5	Kuo-chou	虢州	Ling-pao	靈寶				X		
K50	Shan-chou	陝州						X		
K12	Teng-chou	鄧州						X		
K51	Chün-chou	鈞州	Yü-hsien	禹縣					X	
K6	She-hsien	涉縣					X		X	
K52	Chi-Yuan	濟源							X	
K31	Kung-hsien	鞏縣							X	
K3	Sung-hsien	嵩縣							X	
K19	Nei-hsiang	內鄉							X	
K16	Ju-chou	汝州	Lin-ju	臨汝					X	
L15	Shan-yin	山陰	Shao-hsing	紹興			X		X	
L17	Lin-hai	臨海					X			
L29	Huang-yen	黃岩					X		X	
L30	Ning-hai	寧海					X		X	

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
L31	Chhing-Yuan	慶元							X	
L17	Thai-chou	台州	Lin-hai	臨海					X	
L21	Chhü-chou	衢州							X	
L8	Chhu-chou	處州	Li-shui	麗水					X	
L18	Lung-chhüan	龍泉							X	X
L32	Hsien-chü	仙居							X	
L33	Yung-chia	永嘉							X	X
L34	Jui-an	瑞安								X
L14	Phing-yang	平陽								X
L28	Thai-shun	泰順								X
L35	Yun-ho	雲和								X
L36	Sui-chhang	遂昌								X
L26	Chhing-thien	青田								X
L23	Chien-te	建德								X
M34	Fu-thang	福唐	Fu-chhing	福清			X			
M1	Yu-hsi	尤溪					X		X	
M35	Shao-wu	邵武					X		X	
M18	Chiang-le	將樂					X			
M36	Nan-an	南安					X			
M5	Chhang-thing	長汀					X		X	
M23	Ning-hua	寧化					X		X	
M6	Sha-hsien	沙縣					X		X	
M9	Thing-chou	汀州						X		
M2	Chien-chou	建州	Chien-ou	建甌				X		
M11	Nan-chien chou	南劍州	Nan-phing	南平				X		
M12	Shao-wu chün	邵武軍						X		
M13	Chhüan-chou	泉州						X	X	
M13	Chin-chiang	晉江	Chhüan-chou	泉州					X	
M2	Chien-ning	建寧	Chien-ou	建甌					X	
M37	Hsing-hua	興化	Phu-thien	莆田					X	
M10	Chang-chou	漳州	Lung-hsi	龍溪					X	
M38	Min-chhing	閩清	Fu-chou	福州					X	
M39	Fu-chhing	福清	Fu-chou	福州					X	
M40	Yen-phing	延平	Nan-phing	南平					X	
M41	Kuang-tse	光澤							X	
M21	Ning-te	寧德							X	X
M42	Shang-hang	上杭							X	
M10	Lung-hsi	龍溪								X
M43	Yung-an	永安								X
M44	Ta-thien	大田								X
M45	Yung-ting	永定								X
M46	Yung-chhun	永春								X
N5	Le-phing	樂平					X			
N38	An-yuan	安遠					X			
N8	Shang-jao	上饒					X		X	
N39	Yuan-chou	袁州	Yi-chhun	宜春			X	X	X	
N10	Chhien-chou	虔州	Kan-hsien	贛縣				X	X	
N40	Chi-chou	吉州	Chi-an	吉安				X	X	
N8	Hsin-chou	信州	Shang-jao	上饒				X	X	
N28	Jao-chou	饒州	Po-yang	波陽					X	
N41	Lung-hsing	龍興	Nan-chhang	南昌					X	
N20	Fu-chou	撫州	Lin-chhuan	臨川					X	
N42	Jui-chou	瑞州	Kao-an	高安					X	

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
N43	Lin-chiang	臨江	Chhing-chiang	清江					X	
N44	Chin-hsien	進賢							X	
N45	Hsin-yü	新喻							X	
N46	Fen-yi	分宜							X	
N47	Feng-chheng	豐城							X	
N48	Shang-yu	上猶								X
N49	Chhang-ning	長寧	Hsun-wu	尋烏						X
O31	Ching-shan	荊山	Nan-chang	南漳	X					
O32	Ching-shan	荊山	Tang-yang	當陽		X				X
O48	Pa-tung	巴東					X			
O49	Kuang-chi	廣濟					X		X	
O50	Chhi-shui	蘄水	Hsi-shui	浠水			X		X	
O51	Chiang-hsia	江夏	Wu-chhang	武昌			X			
O42	Yung-hsing	永興					X			
O3	Wu-chhang	武昌	O-chheng	鄂城			X		X	
O24	Chhi-chou	蘄州	Chhi-chhun	蘄春				X		X
O52	Huang-chou	黃州	Huang-kang	黃崗				X		
O4	Hsing-kuo chün	興國軍	Yang-hsin	陽新				X	X	
O43	O-chou	鄂州	O-chheng	鄂城				X		X
O53	Kuang-hua	光化							X	
O1	Ta-yeh	大冶							X	X
O54	Huang-mei	黃梅							X	
O55	Chhang-yang	長陽								X
O56	I-tu	宜都								X
O9	Chu-shan	竹山								X
O57	Ma-chheng	麻城								X
O58	Yang-hsin	陽新								X
O59	Huang-an	黃安								X
O13	Hsien-feng	咸豐								X
O60	Yuan-an	遠安								X
O20	Yun-hsien	鄖縣								X
O16	Yun-hsi	鄖西								X
O18	I-chhang	宜昌								X
O61	Shih-nan	施南								X
P24	Tung-thing shan	洞庭山	Yueh-yang	岳陽	X					
P57	Chhen-hsien	郴縣				X				
P20	Lei-yang	耒陽				X				
P58	Hsiang-yuan	湘源	Tung-an	東安			X			X
P59	Shih-men	石門					X		X	X
P60	Pa-ling	巴陵	Yueh-yang	岳陽			X		X	
P61	Yung-chou	永州	Chhi-yang	祁陽			X		X	X
P62	Yen-thang	延唐	Ning-Yuan	寧遠			X		X	X
P41	Yung-ming	永明	Chiang-yung	江永			X			
P63	Li-chou	澧州						X		X
P64	Tao-chou	道州						X	X	
P31	Yuan-chou	沅州	Tsang-chiang	藏江					X	
P1	Than-chou	潭州	Chhang-sha	長沙					X	
P8	Heng-chou	衡州							X	
P35	Wu-kang	武崗							X	
P36	Pao-chhing	寶慶	Shao-yang	邵陽					X	X
P65	Yung-chou	永州	Ling-ling	零陵					X	X
P40	Chhüan-chou	全州							X	
P10	Chhang-ning	常寧							X	

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
P66	Chha-ling	茶陵							X	X
P23	Liu-yang	瀏陽							X	X
P67	Yu-hsien	攸縣							X	
P51	An-hua	安化							X	X
P68	Ning-hsiang	寧鄉							X	
P22	Li-ling	醴陵							X	
P8	Heng-yang	衡陽							X	
P69	Chhi-yang	祁陽							X	X
P70	Lu-hsi	盧溪							X	
P9	Chhen-hsi	辰溪							X	X
P39	Hsu-phu	漵浦							X	X
P7	Chhen-chou	郴州							X	
P71	Yung-hsing	永興							X	
P4	I-chang	宜章							X	
P72	Kui-yang	桂陽							X	
P14	Chiang-hua	江華							X	X
P73	Yung-ming	永明							X	X
P74	Hsin-thien	新田								X
P75	Sang-chih	桑植								X
P12	Sui-ning	綏寧								X
P35	Wu-kang	武岡								X
P76	Hsin-ning	新寧								X
P77	Hsin-hua	新化								X
P38	Yuan-ling	沅陵								X
P78	Tzhu-li	慈利								X
P79	Yung-ting	永定								X
P80	An-fu	安福								X
P81	Lin-wu	臨武								X
P31	Chih-chiang	芷江								X
Q89	Liang-shan	梁山			X					
Q6	Lin-chhiung	臨邛	Chhiung-lai	邛崍		X	X			
Q91	Wu-yang	武陽	Pheng-shan	彭山		X				
Q17	Nan-an	南安	Le-shan	樂山		X				
Q92	Tang-chhü	宕渠	Chhü-hsien	渠縣		X				
Q23	Thai-teng	臺登	Mien-ning	冕寧		X	X			
Q14	Hui-wu	會無	Hui-li	會理		X				
Q93	Shih-chien	始建	Ching-yen	井研			X		X	X
Q94	Lung-shan	隆山	Pheng-shan	彭山			X			
Q95	Feng-chieh	奉節					X			X
Q96	Nan-pao	南賓	Feng-tu	豐都			X			
Q29	Mian-ku	綿谷	Kuang-yuan	廣元			X			
Q97	Lin-shan	潾山	Lin-shui	鄰水			X			X
Q98	Hsin-chin	新津					X			
Q17	Phing-chhiang	平羌	Le-shan	樂山			X			
Q99	Chia-chiang	夾江					X			
Q100	Lin-hsi	臨溪	Phu-chiang	蒲江			X			X
Q101	Thung-chhüan	通泉	She-hung	射洪			X		X	
Q38	Pa-hsi	巴西	Mien-yang	綿陽			X			
Q18	Hsi-chhang	西昌	An-hsien	安縣			X			
Q14	Chhang-ming	昌明	Hui-li	會理			X			
Q102	Wei-chheng	魏城	Mien-yang	綿陽			X			
Q2	Khun-ming	昆明	Yen-yuan	鹽源			X			
Q11	Shih-ching	石鏡	Ho-chhuan	合川			X			
Q103	Pa-chhuan	巴川	Thung-liang	銅梁			X			

Key to Map 12 (*cont.*).

	Sites		Further identification		Mining Periods					
					P1	P2	P3	P4	P5	P6
Q104	Tzu-kuan	資官	Jung-hsien	榮縣			X			X
Q105	Yung-chhuan	永川					X			X
Q106	O-mei	峨嵋					X			X
Q107	Liu-chiang	流江					X			
Q108	Hsu-chhuan	旭川					X			
Q109	Lu-chhuan	瀘川					X			
Q110	Phan-shih	盤石					X			
Q111	Fu-ling	涪陵					X			
Q112	Ho-chou	合州	Ho-hsien	合川				X	X	
Q113	Tzu-chou	資州	Tzu-chung	資中				X		
Q31	Ya-chou	雅州						X		
Q12	Tzu-chou	梓州	San-thai	三台				X		
Q114	Jung-chou	榮州						X		
Q18	Lo-lo	羅羅	Hsi-chhang tung	西昌東					X	
Q18	Chien-chhang	建昌	Hsi-chhang	西昌					X	
Q28	Lung-chou	龍州	Phing-wu	平武					X	
Q115	Phu-chiang	浦江							X	
Q116	Yen-thing	鹽亭							X	
Q21	Phing-shan	屏山								X
Q27	Chiang-yu	江油								X
Q117	I-pin	宜賓								X
Q24	Yun-yang	雲陽								X
Q118	Wu-shan	巫山								X
Q119	Wei-Yuan	威遠					X			X
Q120	Tzu-thung	梓潼								X
Q19	Hung-ya	洪雅								X
R23	Kui-yang fu	貴陽府	Kui-chu	貴築					X	X
R3	Su-chou fu	思州府	Tshen-kung	岑鞏					X	X
R12	Ssu-nan fu	思南府	Ssu-nan	思南					X	
R24	Shih-chhien fu	石阡府	Shih-chhien	石阡					X	
R4	Thung-jen	銅仁							X	
R9	Sheng-hsi	省溪							X	
R25	Li-phing	黎平							X	X
R19	Phu-an chou	普安州	Phan-hsien	盤縣					X	
R26	An-hua	安化								X
R1	Wei-ning	威寧								X
R20	Khai-chou	開州								X
R21	Hsiu-wen	修文								X
R27	Tsun-yi	遵義								X
S80	So-yang	瑣陽	Ying-te	英德			X			
S7	Kuei-yang	桂陽	Lien-hsien	連縣			X		X	
S8	Yang-shan	陽山					X		X	X
S81	Lien-shan	連山					X		X	
S82	Chen-yang	湞陽					X			
S3	Ying-chou	英州	Ying-te	英德				X		
S63	Mei-chou	梅州						X		
S66	Lien-chou	連州						X		
S4	Shao-chou	韶州						X		
S5	Kuang-chou	廣州						X		
S20	Hui-chou	惠州						X		
S60	Tuan-chou	端州	Chao-chhing	肇慶				X		
S38	Nan-en chou	南恩州	Yang-chiang	陽江				X	X	X
S83	Kui-shan	歸善	Hui-yang	惠陽					X	

Key to Map 12 (*cont.*).

	Sites		Further identification		P1	P2	P3	P4	P5	P6
S84	Chhing-hsi	清溪							X	
S30	Fan-yü	番禺							X	
S85	Chhing-yuan	清遠							X	
S86	Chheng-hsiang	程鄉							X	
S37	Mei-hsien	梅縣							X	
S14	Kao-yao	高要							X	
S1	Yang-chhun	陽春								X
S87	Chieh-yang	揭陽								X
S88	Phing-yuan	平遠								X
S89	Luo-ting chou tung an	羅定州東安	Yun-fu	雲浮						X
S61	Hsin-hsing	新興								X
T35	Huai-chi	懷集					X			X
T1	Kui-ling	桂嶺	Ho-hsien	賀縣			X			
T24	Hsiang-yuan	湘源					X			
T15	Jung-chou	融州						X		
T73	Pao chi shan	寶積山	Jung-hsien	融縣					X	
T11	Yü-lin	鬱林							X	X
T74	Chhüan-chou	全州								X
T55	Wu-chou	梧州								X
U44	Tien-chhih	滇池	Chin-ning	晉寧		X				
U63	Pu-wei	不韋	Pao-shan	保山		X				
U3	Ai-lao	哀牢				X				
U43	Yung-phing	永平				X				X
U57	Chung-chhing	中慶	Khun-ming	昆明					X	
U4	Ta-li	大理							X	
U11	Chin-chhih	金齒	Pao-shan	保山					X	
U47	Lin-an	臨安	Thung-hai	通海					X	
U48	Chhü-ching	曲靖							X	
U1	Chheng-chiang	澄江	Chheng-chiang	澄江					X	
U57	Khun-ming hsien	昆明縣							X	
U64	Ho-hsi	河西							X	X
U65	Hsi-o	嶍峨	O-shan	峨山					X	
U36	Hsin-hsing chou	新興州	Yü-hsi	玉溪					X	
U66	Meng-hua	蒙化							X	
U31	Lu-liang	陸良							X	X
U12	Hui-tse	會澤							X	
U67	Chan-i	沾益							X	
U8	Wu-sa	烏撒							X	
U68	Chen-nan	鎮南	Hua-nan	華南						X
U69	Ma-lung	馬龍								X
U70	Shih-phing	石屏								X
U29	Theng-yueh	騰越	Theng-chhung	騰衝						X
U15	Ta-kuan	大關								X
U62	Ho-chhing	鶴慶								X
U19	I-men	易門								X
U26	Nan-an	南安	Shuang-pai	雙柏						X
U71	Wei-yuan	威遠	Ching-ku	景谷						X
U27	Ting-yuan	定遠								X

Table 9. *Major iron minerals of traditional China*

Mineral	Max. theoretical iron content	Comments
Magnetite Fe_3O_4	72.4%	Occurs most commonly with hematite, especially in post-Carboniferous (more recently than 280 million years ago) contact metamorphic deposits of eastern and central China. Also found abundant as ironsands in Fukien and Chekiang and in hydrothermal deposits of the southwest. Most magnetic of all minerals, sometimes to the point of constituting a natural magnet with polarity (lodestone). Lodestone was however rare and highly prized in traditional China.
Hematite Fe_2O_3	70.0%	The most abundant in quantity and distribution of all Chinese iron ore minerals. Especially important deposits include (1) the relatively easy-to-work Carboniferous (345–280 million years ago) 'Shansi type' ores consisting of nodular and mammillary masses of hematite, limonite and siderite found throughout north and central China; (2) the hard and difficult-to-work but sometimes very high grade post-Carboniferous contact metamorphic deposits of eastern and central China, especially along the lower Yangtze; and (3) the riverbed ironsand deposits of southern Hunan and Fukien/Chekiang (though here magnetite often predominates).
Limonite $Fe_2O_3 \cdot H_2O$	62.9%	Omnibus term for a range of hydrated iron oxides or iron hydroxides, including gossan ('iron hat'), bog iron ore, red and yellow ochres, and laterite. The first two especially were important in the iron industry of Kwangtung in late imperial times, especially since the Kwangtung deposits were largely free of impurities such as sulphur and phosphorus. Many of the Shansi iron deposits were mainly limonite.
Siderite (chalybite) $FeCO_3$	48.3%	The iron carbonate which, unweathered, would be indistinguishable from limestone to early miners. It weathers, however, to easily recognisable limonite nodules. In rich deposits at Tang-yang in Hupeh.
Pyrite FeS_2	46.6%	The hard iron sulphide used in China mainly for the production of sulphur (it can contain up to 54.24% sulphur). Known as 'fool's gold' because it can easily be mistaken for gold by inexperienced miners and prospectors.

Based on Hsia Hsiang-jung *et al.* (*1980*), pp. 224 ff.; Tegengren (1924), pp. 7–11 and 302–3; Rastall (1923), pp. 313 ff.; Bauman (1976), p. 121; Read (1910a), p. 199; Dolbear *et al.* (1949), pp. 1003–4; Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 266–7. For the extensive Chinese terminology for these minerals, see Vol. 5, pt. 2, pp. 162 ff.

Map 13. Areas in China proper for which there is evidence of iron industries based on ironsand at one or another time in Chinese history. Based on Wagner (1985), p. 29 (sources given on p. 28).

Donald Wagner has constructed a map of all the areas in China for which he was able to find evidence of an iron industry based on ironsand at one time or another in Chinese history (Map 13). As he points out, ironsand ore was rather uneconomic by comparison with other kinds of iron ore, but it served well as the basis of a sideline occupation for peasants during the slack seasons in the farming cycle.[464] Since an iron concentrate could be obtained by panning or sluicing, this mining required little in the way of special skills and only minimal expenditures for tools, sluices and the like (Fig. 15). An industry could emerge in any place where certain economic and geological conditions were met: large placer deposits and an absence of easily mined (and therefore more efficient) ore outcrops; a sufficient local demand that could not be met by other sources, perhaps because of transportation costs that also made alternative sideline or full-time local industries uncompetitive; and sufficient water for washing the ore as well as fuel for smelting.[465]

[464] Wagner (1985), p. 28. See also Hsia Hsiang-jung *et al.* (*1980*), p. 230; Tegengren (1924), pp. 302–4.

[465] Wagner (1985), p. 28. Early references specifically to the mining of ironsand are surprisingly rare, with nothing at all before the early +16th century; *Ibid.*, p. 31. The Japanese *tatara* iron-smelting process, used until 1921, also made use of ironsand; *Ibid.*, p. 32.

Fig. 15. Concentrating iron ore by washing. Sun & Sun (1966), p. 249 (original illustration; see *TKKW*, ch. 14, p. 257 for the same illustration redrawn more skilfully but with no further technological detail). Donald Wagner (1985, p. 31) notes that *panning* ironsand in still water would have required enormously more labour than *sluicing* by means of running water, and suggests that this illustration may not have been based on actual practice but may rather be the imaginative portrayal by an artist who was familiar only with gold panning. Another possibility suggested by gold washing practices still in use today is that what is being panned here is actually ironsand that had already undergone preliminary beneficiation or concentration by means of sluicing. Skilful panning can produce a much higher grade of concentrate than sluicing. (On the face of it, this does not appear to be a very likely explanation, a conclusion reinforced by Tegengren's description of ironsand washing in Hopeh which seems quite clearly to indicate that only sluices were used, with no further panning; Tegengren (1924), p. 180.) In any case, both the original and the redrawn illustrations for the *Thien Kung Khai Wu* 天工開物 are still misleading in two ways: (1) in suggesting that the washing box is nearly full of ore, which would render it too heavy to be manipulated effectively; and (2) in having the washer in a standing rather than in a squatting position, which would be very hard on the back (cf. Fig. 31 below).

Much of China's iron ore had not only been enriched but also rendered soft and even crumbly through long periods of weathering. China's iron deposits were so abundant that, after more than 2,000 years of exploitation, Sung Ying-hsing 宋應星 was still able to write at the beginning of his discussion of iron in the *TKKW*: 'Iron mines are found everywhere. Iron outcrops at the earth's surface rather than being found in deep cavities. It is plentiful on low, sunny hillsides but not to be found on high and precipitous mountains.'[466] Actually, Sung was engaging in a bit of over-generalisation here. In suggesting the absence of deep iron ore deposits in China, he was quite mistaken.[467] Such deposits were not even all that rare. In Shansi, for example, iron ore or at least the best iron ore was usually found below the coal measures.[468] Even these deposits, however, tended to consist of soft and easily mined ores.[469]

China also had iron ores that were so highly resistant that they could not be mined using traditional methods[470] or were ignored in favour of less rich but softer and therefore more easily worked deposits.[471] Some of these resistant deposits, though well-known, survived into this century as durable features in the Chinese landscape (Fig. 16). Even in the case of recalcitrant ores, however, the eroding action of natural forces over a long time often produced a surface or near-the-surface rubble consisting of pebbles of a size that could be directly used in smelting furnaces and therefore made possible the use of these deposits from a very early period.[472]

The archaeological remains available in the late 1980s and early 1990s enabled Donald Wagner to make a persuasive case that Chinese iron production could have developed first in southeast China.[473] Interestingly, this hypothesis echoed the views expressed by one of the pioneers of modern geology in China, Wong (Ong) Wen-hao,[474] in the early decades of this century.[475] In the light of later archaeological evidence, however, Wagner has now abandoned this hypothesis.[476] He and many other scholars would now incline to the idea that iron smelting arrived in northwest China from the West by means of Scythian intermediaries. In any case, wherever the first iron production took place, there is no denying its rapid and extensive

[466] *TKKW*, ch. 14, p. 239, translation following Yabu'uchi (*1969*), p. 269 rather than Sun & Sun (1966), p. 248. See also Hsia Hsiang-jung *et al.* (*1980*), p. 230. On the other hand, very little mining of ironsand was taking place in China by the beginning of the 20th century. In part, this may have been due to the increasing availability of cheaper iron, domestic or foreign (Wagner (1995), pp. 139–42), but may also have resulted from the working out of ironsand deposits over some two and one-half millennia.

[467] Of course, Sung would only have known about deposits already exploited, either in the past or in his day, and the economics of iron production for the most part precluded the exploitation of iron ores deep underground. The same would tend to be true for deposits on high mountains, which also existed.

[468] von Richthofen (1875), p. 15; Read (1939–1940), p. 128.

[469] Tegengren (1924), pp. 302–3. As Wagner notes (1993, p. 258), deep-mining is seldom necessary to obtain the amount of ore required for typically small scale premodern production levels, say a few hundred tonnes of pig iron per year.

[470] Tegengren (1924), p. 240. [471] Rostaker & Bronson (1990), p. 44. [472] Tegengren (1924), p. 323.

[473] Wagner (1993), esp. chapters 2 and 3. This book is now the indispensable reference for surviving pre-Han iron artefacts in China.

[474] Bain (1933), p. 86; Golas (1982a), p. 37; Yang Zunyi *et al.* (1986), pp. 3–4.

[475] Weng suggested that the quality and ease-of-working of the iron ore deposits in south China as well as the abundance of wood to be used as a fuel in smelting spurred a more rapid development of iron production there. Hsia Hsiang-jung *et al.* (*1980*), p. 216.

[476] Personal communication, August, 1995.

(a)

(b)

Fig. 16. Examples of China's very tough iron ores: (*a*) A protuberant cliff of iron ore at Thung-kuan shan, Thung-ling 銅陵 hsien, Anhwei; (*b*) Iron ore outcrop at Yü-phing shan, O-chheng 鄂城 hsien, Hupeh. Tegengren (1924), pls. xxiv, xxvii.

spread throughout China in the following centuries.[477] To be sure, it was some time before Chinese smelters were able to produce iron (and steel) of a quality that made possible a general substitution of iron for bronze in weapons.[478] Even a poorer quality of iron, however, was more than adequate for most agricultural and craft tools, provided it was cheap. Here one sees a rapid spread in the use of iron during the −3rd century.[479]

[477] Anon. (*1978b*), pp. 44–6; Hsia Hsiang-jung *et al.* (*1980*), pp. 29–30; Chang Kwang-chih (1977), p. 352. On the controversy over whether the rise of the state of Chhin in the −3rd century owed a great deal to an ability to produce technically superior iron weapons, see now Wagner (1993), pp. 255–6.

[478] Resistance to corrosion and the fact that bronze swords could be cast into semi-finished form while iron swords could not may also have led sometimes to a choice of bronze over iron swords; Rostoker & Bronson (1990), pp. 3, 10.

[479] Wagner (1993), pp. 244–5.

The archaeological remains demonstrate that, as more iron became available, the Chinese preferred cast iron for most everyday uses (such as shovel or hoe blades, ploughshares, axe- and arrowheads) but used wrought iron extensively for bladed objects (for example, swords and knives) and luxury products.[480] This contrasts dramatically with the situation in the West, which relied until the late medieval period (+13th and +14th centuries) almost exclusively on wrought iron. The cheapness of the implements produced by casting – a major step forward in the history of mass production[481] – encouraged a level of iron usage among the population at large that would have been unthinkable if China had had to rely on the more expensive smithy-produced wrought iron.

Increasing familiarity with iron led in the later Warring States period (at the latest by the −3rd century) to two extremely important discoveries: (1) how to produce by means of annealing (heating briefly to a red heat, followed by slow cooling to reduce brittleness) a malleable cast iron that was 'a cheap and only slightly inferior substitute for steel in many applications';[482] and (2) how to produce steel itself as well as how to harden it by quenching (plunging the red- or white-hot steel into a cooling liquid) and then to reduce its brittleness by tempering (reheating the object to a lower temperature).[483]

Demand triggered by much improved iron and steel led to the further development of iron mining. For example, we know that, at the famous −1st millennium copper-mining site at Thung-lü shan 銅綠山 (see above, Section (*e*)(1)(i)(δ)), the transition from bronze to iron tools was well under way by the middle or end of the Warring States period.[484] We have another reflection of the rapid spread of iron mining in the *Kuan Tzu* which says that at that time (−3rd or −2nd century [?]) there were 3,609 mountains that produced iron but only 467 that produced copper.[485]

By the closing years of the first century of the Western Han, iron production had become a major industry of sufficient concern to the government that, in −117, it became, along with salt, one of the first two products over which the Han government attempted to establish a 'monopoly'. Exactly how this monopoly worked is difficult to ascertain with any certainty since the texts referring to it consistently lack precise details. In any case, the Han iron monopoly set a precedent for large-scale

480 Hua Chueh-ming (*1987*), p. 68; Wagner (1985), p. 45. In later periods, Chinese increasingly used wrought iron for objects which had previously been made of cast iron; Anon. (*1978g*).

481 Gernet (1982), pp. 69–71; Barnard & Satō (1975), p. 67.

482 Wagner (1989), p. 3; Wagner (1993), p. 406; Rostoker (1988).

483 Wagner (1993), pp. 277, 279. Just possibly, it may also have been in the Warring States period that the Chinese began to use anthracite coal for smelting iron in crucibles (Hartwell (1966), p. 52; Hartwell (1967), p. 119), thus opening up an important new source of fuel for smelting. However, it is still a matter of dispute as to whether crucible smelting was practised even as early as the Han, not to speak of the Warring States period; Wagner (1993), pp. 289–90.

484 Hsia Hsiang-jung *et al.* (*1980*), p. 25.

485 *Kuan Tzu*, ch. 23, p. 1a; Hsia Hsiang-jung *et al.* (*1980*), p. 31; Than Po-fu *et al.* (1954), p. 145. The last mistakenly has 3,690 iron-producing mountains. One would hardly want to overestimate the accuracy of this 'count' but the general impression of very extensive iron mining undoubtedly reflects the real situation in late Warring States China. Given the abundance of easily worked iron deposits, iron mining continued to predominate over copper mining in terms of number of mines and miners throughout Chinese history; for the Sung (+10th to +13th centuries), see Hino (*1935a:1983*), p. 321.

government intervention in mining activities, a precedent which Chinese governments would follow time and again over the next 2,000 years to meet their needs for revenue or for supplies of metals.

This was certainly the case in the Northern Sung (+960 to +1126) when both government and private demand for iron rose dramatically.[486] The government needed vast amounts of iron for weapons and armour to equip the largest standing army in the world, for its iron currency, for cast iron pans to evaporate salt, and for many other industrial uses.[487] From the second half of the +11th century and in the following century, large quantities of iron, some even smelted specifically for the purpose, were used in the cementation process for producing copper from vitriol waters and earths.[488] Peasants and craftsmen used a wide range of iron and steel tools and implements, including knives, hatchets, chisels, adzes, drillbits, hammers and mallets, ploughshares, hoes, spades and shovels, harrows, rakes, sickles, wheelbarrow axles, horseshoes, wheels, cooking pots and pans and kettles. Iron was also to be found in bells,[489] chains (including those for chain suspension bridges), armoured gates, watchtowers, bridges, nails, needles, rulers, printing frames and type, wire, mirrors, and religious images.[490] To meet its own needs and the growing popular demand, the government for the first time lent strong encouragement to the exploitation of the vast iron ore deposits of Shansi where the ore was not only easily mined but had the advantage of being accompanied both by abundant coal seams that could serve as fuel for smelting operations as well as by a variety of clays and sands also useful for smelting.[491]

Scholars have disagreed about the levels of iron production reached in the Sung and afterwards. Robert Hartwell has suggested that the amount of iron produced in the Northern Sung was 'probably greater than in any other period in pre-19th century Chinese history'.[492] Hartwell's estimates, however, quite possibly exaggerate iron production during this period.[493] They probably underestimate the production of later centuries, and are certainly unreliable for the 20th century.[494] It is more likely

[486] Overseas demand was also a factor, though we cannot say how great. We do know that, until recent times, China provided virtually all the cast iron used in southeast Asia; Bronson (1993), p. 89.

[487] Hartwell (1962), pp. 155, 157–9; Hartwell (1966), pp. 37–8. As Alexander Hosie points out, the manufacture of these pans required a great deal of iron. The largest were 1.5 to 1.75 m in diameter and could weigh up to 725 kg! They constantly had to be replaced, and even allowing for the iron recycled from old pans, that meant substantial consumption of new iron on a regular basis; Hosie (1922), p. 169.

[488] Section (*j*) below. [489] Rostoker *et al.* (1984).

[490] Hartwell (1962), pp. 154–9; Tegengren (1924), pp. 311–12; Hsiung Chhuan-hsin *et al.* (*1985*), p. 124, Wang Chung-shu (1982), pp. 123–4; Hartwell (1963), p. 44. By Sung times if not earlier, there was a great deal of regional and local specialisation in the production of iron products; Chhi Hsia (*1987–1988*), Vol. 2, pp. 553–5; Hartwell (1963), p. 28.

[491] Tegengren (1924), p. 306.

[492] Hartwell (1962), p. 154. Compare Wagner (1993a, p. 306) which makes the important point that we will have to know much more about the administrative apparatus that produced the figures on which Hartwell bases his estimates before we can decide with some confidence how much credence to lend to them.

[493] Chhi Hsia, on the other hand, thinks Hartwell's figures too low. He would 'guestimate' maximum production in the late +11th century of up to 700,000 tonnes per year! (Chhi Hsia (*1987–1988*), Vol. 2, pp. 553, 555.) Unfortunately, he provides us with no evidence for his key assumption, namely that each farm family at that time used, on the average, ten *chin* (about 6 kg) of new iron each year.

[494] Personal communication from Donald Wagner who has checked Hartwell's source *and its source*, and found the latter to be very unreliable.

that iron production in China increased from the Sung period on, though at nothing like the twelvefold rate of growth that Hartwell estimates for the two centuries between +850 and +1050.[495] We are probably on safer ground then to conclude that the peak in iron production during the traditional period was probably reached in the 18th century, followed by a significant decline because of the unsettled conditions in the 19th and early 20th centuries.[496]

In the larger context of the history of technology in China, it is important to stress that, from a very early period, iron mining and smelting frequently took place on a scale seldom if ever seen in other contemporary societies, or in other Chinese industries, at least until the Sung. In part, this was surely the result of the quantities of iron that could be worked into weapons and tools and coins in the mass production casting operations.[497] Even before the nationalisation of the industry by Emperor Wu of the Han, a private mine could employ a thousand or more miners

[495] Hartwell (1962), p. 155. The earlier pace is reminiscent of the quintupling of silver production in central Europe between +1450 and +1550; Suhling (1977), p. 571.

This is not the place for a detailed dissection of Hartwell's estimates. We might simply note a few caveats: (1) That Hartwell himself can make his estimate no more precise than from 75,000 *to 150,000* tonnes of total yearly iron production around +1078 should alert us to the limitations of his data. A major problem is that we simply have no real idea how much private iron production occurred outside the taxing system whose receipts form the only basis we have for iron production estimates. My own guess is that such untaxed private production was widespread but very small-scale, meaning that the total amount of iron produced in this sector was relatively limited. In per capita terms, it was surely *very* small, though there may have been fairly significant variations from region to region. Yoshida Mitsukuni stresses the low overall per capita production in rejecting the idea that the increase in iron and coal production in the Sung constituted a 'revolution' (Yoshida (*1966*), p. 521). Looking narrowly at the technology used, the undoubted advances that occurred also hardly seem to add up to revolutionary change. (2) The estimate of 75,000 tonnes of taxed iron production around +1078 compares strangely with the 90,400 tonnes of total taxed production (*not* total production as Hartwell presents it) estimated for +1064 to +1067 (Hartwell (1966), p. 32). Was there really a 17% decline in taxed iron production between +1067 and +1078? If so, what accounts for it? (3) At the heart of Hartwell's estimate are certain assumptions for which the evidence is anywhere from meagre to altogether absent. An example is the existence *and general enforcement* of a 10% rate for each of the two taxes the government assessed on iron. Indeed, it is far from certain that the surviving figures *do* represent two different taxes, an idea rejected by Hino and Yoshida. (Hino (*1935*), p. 292; Hino (*1935a*), pp. 326–33; Yoshida (*1966*), pp. 519–21.) On the other hand, there is evidence that the Yuan had a separate tax system for privately owned mines (Schurmann (1956), pp. 147–9), and it would not be surprising the find that it derived from Sung practice. (4) As Tim Wright has pointed out, Hartwell's suggestion that gross iron production declined after the Sung would imply a very sharp decline in per capita consumption of iron (because of the quadrupling of population between +1000 and +1800). For this too, there is little evidence. In addition to the possibility that he may have overstated Northern Sung production, Hartwell may also not have allowed sufficiently for the extent of growth of iron production in other areas of the country even as it declined in some of those places that flourished during the Sung (Wright (1984), pp. 7–8). For example, the really great development of the productive capacity of Shansi, of Ta-yeh 大冶 (just south of the Yangtze), and of Fo-shan 佛山 (in Kwangtung) was in Sung times still in the future. (W. Smith (1926), pp. 48–9; Jameson (1898), p. 365; Read (1912), pp. 25, 29–33; Nishizawa (1912–1913), p. 1022; Hartwell (1966), pp. 35–6, fn. 17; Hartwell (1963), p. 567; Hsia Hsiang-jung *et al.* (*1980*), pp. 121, 149–50). Hartwell is of course aware that mining sites should be expected to shift over time because of, among other reasons, exhaustion of the ores (e.g. Hartwell (1963), p. 170). He even notes later major centres of production that were hardly exploited in the Sung (Hartwell (1963), p. 57). The question is how much these new sites compensated or even more than compensated for lost production at certain mines that had been important in the Sung.

[496] Wagner (1984), pp. 103–4. Possibly relevant here is the fact that, by the early Ming, the government had so much iron on hand that it abolished state-run iron smelting throughout the empire; Hsia Hsiang-jung *et al.* (*1980*), pp. 28, 147, 172–3.

[497] True mass production of metal objects may even have begun as early as the Shang if, as Wagner contends, the dagger-axe (the main weapon of Bronze Age China) was indeed 'clearly designed for mass production'; Wagner (1993), p. 405.

and many of the great private fortunes made at that time were based on iron mining and smelting.[498] In the Sung and Yuan periods, it was not uncommon for hundreds or even thousands of households to be assigned to a given area to mine and smelt iron.[499] But even in those cases where there were large numbers of iron miners engaged in major iron mining and smelting operations, the characteristic methods of mining, if not necessarily smelting, tended to be small-scale in both organisation and technology.

Because most of China's iron mining focused on shallow deposits of soft, easily worked ores, it posed fewer technological problems than many other kinds of mining. What was effectively 'ore gathering'[500] could easily be carried on by peasants working the deposits with very simple tools as a by-employment during the slack seasons for agricultural work.[501] It is worth noting that both of the illustrations in *TKKW* dealing with iron mining involve very simple surface operations: the picking up of small chunks of bog iron ore detected while ploughing fields (Fig. 17) and the concentration of iron ore by washing (Fig. 15).[502]

It is therefore the smelting rather than the mining of iron that is of paramount interest in the history of technology in China.[503] That story will be told in the examination of ferrous metallurgy in Section 36b. Iron mining will concern us in the following pages mainly to illustrate certain practices that were widely used in much of traditional China's small-scale metal mining.[504]

(i) *Minor ferroalloy and non-ferrous metals*

Evidence for any Cinese mining before the end of the 19th century of metals and transition metals such as tungsten, antimony, bismuth, manganese or magnesium is virtually non-existent. As noted above,[505] some of these metals were ignored by one of our best sources for information on early Chinese mining, the pharmaceutical

[498] Needham (1964), p. 7.

[499] Collins (1922), pp. 21–2; Schurmann (1956), pp. 147, 157–9. The texts ordinarily do not make clear what proportion of these 'smelter households' (*yeh hu* 冶戶) were involved in mining and what proportion were involved in smelting. Some probably alternated between the two activities.

[500] Wagner (1993), p. 258.

[501] In the early 20th century, boulders of ore containing 50% iron could still be picked out of stream gravels in Shansi; Read (1910a), p. 199. Coghlan felt that the same situation of 'the ore being merely collected from surface workings' probably prevailed in the first mining of iron in Europe; Coghlan (1956), pp. 16–17.

[502] For the same phenomenon in England, cf. Clark (1952), p. 201.

[503] For example, the first water powered bellows in China were used in iron smelting at least by the beginning of the Eastern Han; Anon. (*1978b*), pp. 101–2.

[504] In connection with small-scale mining, one should also note the recent thesis propounded by Donald Wagner that one of the important advances in iron smelting in the post-Han period was the development of *small-scale* smelting techniques such as small blast furnaces and crucible smelting; Wagner (1995), p. 155. If this was the case, it would have had at least three important results: (1) an increase in the exploitation of small and not particularly good iron deposits, (2) making iron mining and smelting an attractive full- or part-time activity for large numbers of China's peasants and, at the same time, (3) assuring a great deal of iron production beyond the government's control or even its knowledge. This last could even include extensive local private minting of iron coins such as was very widespread in Kwangtung in the Chhing; Kuo Yun-ching (*1984*), p. 79.

[505] Vol. 5, pt. 2, p. 190.

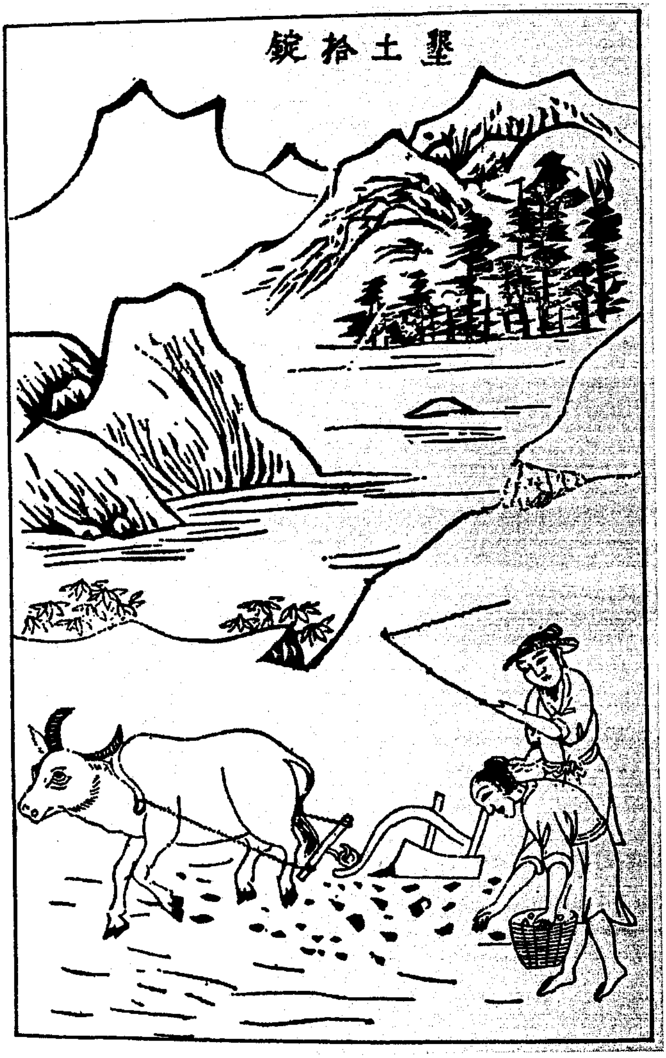


Fig. 17. Ploughing up pieces of bog iron ore; Sun & Sun (1966), p. 249.

natural histories (*pen tshao* 本草), because they had no known medical value. Moreover, although they were not in common use, these metals may well have been known to alchemists who had a professional stake in keeping their knowledge secret. Thus, despite China's dominance of the world tungsten market after World War I,[506] no mention of a tungsten ore seems to appear in earlier literature.[507] The sources are also silent on bismuth.

Terminology is a problem here as elsewhere. The ores of some of these metals may well have been known by folk names in the areas where they were found and where perhaps even local industries based on them may have grown up. These and other names may have been lost or may be very difficult or impossible to identify when they appear. One example is the antimony sulphide, stibnite, which may be what is referred to by the terms *hsi lin chih* 錫吝脂 or *hei shih chih* 黑石脂 in the +16th century *Pen Tshao Kang Mu* 本草綱目 (The Great Materia Medica).[508]

The case of stibnite reminds us, moreover, that ores containing small amounts of these metals were sometimes used without the metals being recognised. This could happen even with major ores of these metals. Antimony is easily processed from stibnite, of which there are major deposits especially in Hunan, but it is easy to confuse antimony and lead.[509]

In contrast to the metals discussed above, we *are* able to identify fairly accurately the beginnings of cobalt mining in China, though we have few specifics about pre-20th century mining.[510] The Chinese began to use cobalt as a pigment for glass beads as early as the Warring States period. Afterwards, it came to serve widely as a pigment for ceramic glazes and underglaze colours. Before the Ming, however, all the cobalt pigments used contained copper or arsenic as associate elements but little or no manganese. Ores that would provide such pigments are characteristic of the cobalt ores of Iran, Iraq, Syria and Turkey. With the Ming, however, we begin to see cobalt glazes where the manganese is extremely high, which is typical of Chinese cobalt ores, especially absolite, which can contain three times as much manganese as cobalt. This has led scholars to conclude that pre-Ming cobalt used in China probably came from Persia or other western Asian sources,[511] and that it was not until perhaps the +15th century that Chinese cobalt ore was first discovered.

[506] Lilley (1936), p. 432.

[507] The most likely reason is that the recognition of tungsten was inhibited by its very high melting point of at least 3,390 °C, the highest of any metal.

[508] Vol. 5, pt. 2, p. 190 and p. 267, fn. f.

[509] Wei Chou-yuan (1946), pp. 445–6; Lu Hsueh-shan (*1984*), p. 20; Derry & Williams (1960), p. 141; Forbes (1954), p. 85. Even some references to silver mines in the Chinese sources may actually refer to antimony ore; Hsia Hsiang-jung *et al.* (*1980*), p. 209. The barium ores of barite (the sulphate) and witherite (the carbonate) are present in north China and in Korea, and barium is frequently present in Chinese glass of the Warring States period, but whether the Chinese glassmakers introduced it intentionally is still an open question; cf. Vol. 4, pt. 1, pp. 101–3.

[510] The general concensus on the beginnings of mining for cobalt in China can be seen by comparing Young & Garner (1956) and Zhang Fu-kang (1988).

[511] Not surprising, since commercial contacts between China and that area began as early as the −11th century; Zhang Fu-kang (1988), p. 122.

(3) Jade and Gemstones

(i) *Jade and jade-like stones*[512]

The Chinese had begun fashioning objects of jade at least by about −5000.[513] By the end of the Neolithic period, jade had clearly established its primacy among the semi-precious stones suitable for 'carving' and it would continue to grow in importance in the succeeding centuries.[514] One testimony to this fascination with jade itself and to the emergence of jade as a standard for judging other stones is that the original Han dynasty (+2nd century) *Shuo Wen Chieh Tzu* (Analytical Dictionary of Characters) contains some 126 characters with the jade radical (the component of the Chinese character that is related to its meaning), many of which are identified as kinds of jade (*yü* 玉) or as stones resembling jade.[515] The *SHC* also mentions a great variety of jades and jade-like stones identified by the Chinese at least by Warring States or early Han times.

Very little jade was found in China in traditional times. Some tremolite (of which nephrite is a compact variety) and actinolite were mined in the Lake Thai (Thai Hu 太湖) region in Neolithic times.[516] It has also been noted that a number of the jades discovered in the excavations of Shang An-yang 安陽 seem to be very similar to the jade mined at Hsiu-yen 岫岩 in Liaoning while a smaller number are similar to jade found at Nan-yang 南陽 in Honan.[517] Nevertheless, virtually all the jade used by Chinese stoneworkers at least from the Chou onwards[518] and until quite recent times came from rivers and mountains of Khotan (Ho-thien 和田) and Yarkand (So-chhe 莎車) in present-day Sinkiang.[519] Until perhaps the Thang or Sung period, it seems to have been obtained exclusively by collecting jade pebbles or larger rocks from river beds. Later it was quarried, using firesetting to produce cracks and fissures into which wedges could then be driven to break up the stone.[520]

Because of the rarity of jade deposits in the Chinese heartland, jade played no significant direct rôle in the history of Chinese mining. It was important indirectly, however, in two ways: (1) its combination of prestige and rarity led Chinese to search

512 An excellent, up-to-date starting point for what is known about the history of jade not only in China but throughout the world is Keverne (1991). It is lavishly illustrated (ALL illustrations in colour) and its useful, annotated bibliography (pp. 356–67) includes a number of Chinese works. It also provides (p. 31) a detailed chart giving the properties of jade and its simulants.

513 Hsia Hsiang-jung *et al.* (*1980*), p. 416; Ho Yueh-chiao & Chu Fu-Hsi (*1986*), p. 22. For the modern distinction of jades into nephrite (*juan yü* 軟玉, *chen yü* 真玉) and jadeite (*ying yü* 硬玉), cf. Keverne (1991), pp. 22–7; Cheng Te-khun (1960), pp. 111–12; Clark (1986), pp. 33–4.

514 Cheng Te-khun (1976), p. 48. The Chinese shared this high esteem of jade with three other groups of people: the Neolithic inhabitants of much of temperate Europe; the Maori of New Zealand; and the inhabitants of Mexico from Mayan times onward. Clark (1986), p. 34.

515 Hansford (1950), p. 26. In its common, broad usage, *yü* could mean any stone suitable for carving; Keverne (1991), p. 22.

516 Chang Kwang-chih (1986), p. 255. Chang uses 'jades' loosely here to include also chrysotile (which is a serpentine) and agate (which is a variety of chalcedony).

517 Hsia Hsiang-jung *et al.* (*1980*), pp. 420, 428–9. 518 Hsia Hsiang-jung *et al.* (*1980*), p. 430.

519 Vol. 3, p. 665; Hsia Hsiang-jung *et al.* (*1980*), pp. 421ff.; Dana (1971), p. 389.

520 Hansford (1950), pp. 38, 41.

widely for other stones that most resembled jade;[521] and (2) the Chinese love of 'carved' jade, which is not carved at all since jade, either nephrite or jadeite, is too hard to be cut even by steel tools alone, led the Chinese to search for the most effective abrasives that could be used for shaping it (*ti-li cho* 砥礪琢).[522]

Neolithic stone carvers used many other minerals and stones along with jade to make ornaments.[523] A very early example comes from the Ho-mu-tu 河姆渡 culture south of Hang-chou 杭州 Bay where fluorite was used along with jade to make ornaments.[524] At another site, near Nanking, jade and agate were used together.[525] Especially popular, apart from coal, which we shall discuss below, seem to have been serpentines, various chalcedonies, especially agate, pyrophyllite (a kind of talc), and steatite (soapstone).[526]

(ii) *Other precious or semi-precious stones*

The mining of other precious or semi-precious stones requires no detailed treatment here.[527] Even in the West, where many kinds of gemstones seem to have exercised a much greater attraction than among the Chinese, they commonly could be and were obtained from placer or surface deposits or through trade from border regions and beyond.[528] Only a few such as turquoise were sought in underground deposits or obtained as by-products of other underground mining.[529]

[521] Chinese returning home after having worked as miners in 19th century California often brought with them greenstone pebbles they had collected along the Fraser River; Clark (1986), p. 53.

[522] By Shang times, jade carvers could work with stones even harder than nephrite and jadeite; Cheng Te-khun (1960), p. 113.

[523] Jade and jade-like stones were occasionally also used as tools; *Ibid.*, pp. 94–5.

[524] Hsia Hsiang-jung *et al.* (*1980*), p. 416. [525] *Ibid.*, (*1980*), p. 416.

[526] Hansford (1950), p. 26; Rawson & Ayers (1975), p. 14; Loehr (1965), p. 77; Hsia Hsiang-jung *et al.* (*1980*), pp. 414–15. Serpentine, steatite and agates in particular were relatively abundant at least in certain parts of China. Hansford (1950), p. 26; Becher (1887), pp. 37–8; *TKKW*, ch. 18, pp. 308–9; Sun & Sun (1966), pp. 304, 307. Sung Ying-hsing claims that agate is neither stone (*shih* 石) nor jade (*yü* 玉) but does not indicate why he believes this or to what other category of materials it might belong.

[527] For some general discussion, cf. Vol. 3, pp. 669–70.

[528] *TKKW*, ch. 18, p. 306; Sun & Sun (1966), pp. 299–300; above, Vol. 3, p. 670. Much of Sung Ying-hsing's treatment of gems, such as his apparent belief that they regularly give off a misty vapour (*pao chhi ju wu* 寶氣如霧) that is particularly dangerous for miners, suggests that he had little more first-hand knowledge of gem mining than of jade prospecting which, he tells us, could be especially effective in the autumn moonlight since the lustre of jade derives from the shining essence of moonlight! *TKKW*, ch. 18, p. 307. Sun & Sun (1966) mistakenly have the jade itself being formed by moonlight; Sun & Sun (1966), p. 300.

[529] Forbes (1963), p. 108. Turquoise seems to have been highly regarded especially in early China, though it was never as popular as jade; Rawson & Ayers (1975), p. 6. Besides being shaped into ornaments from the Neolithic period on, it was also, unlike jade, often used for inlay work; see examples in Cheng Te-khun (1976), pl. Id; Chang Hung-chao (*1927*), pl. II; Chang Kwang-chih (1986), p. 316 and White (1945), pp. 98, 198–9. Perhaps the earliest piece of inlay work so far found in China is an oracle bone from the reign of the Shang king *Ti Hsin* 帝辛 (–11th century); the bone is prepared from the humerus of a tiger, presumably the one taken in the hunt referred to on the bone, and the inscription is inlaid with turquoise. See Jacobsen (1984), p. 43. There seems to be very little information available on the mining of turquoise in traditional China, probably because most of it was obtained from copper mines. (Turquoise is a hydrated copper aluminium phosphate.) For a general discussion of turquoise in China, focusing mainly on terminology and areas of production, see Hsia Hsiang-jung *et al.* (*1980*), pp. 430–42. Grahame Clark is quite mistaken in saying that the Iranian plateau was the nearest source of turquoise for the Chinese at the beginning of the Shang period; see Clark (1986), p. 35.

(4) Miscellaneous Non-metallic Minerals

(i) *Arsenic*

Most of the arsenic used by the Chinese in imperial times was obtained from the bisulphide realgar and the trisulphide orpiment which are frequently associated one with the other.[530] The major production areas were Kansu in the northwest, Hunan in the south, and the southwestern provinces of Kweichow, Szechwan and Yunnan. Unfortunately, we have virtually no information in the written sources on arsenic and its ores before the Han period. For example, it is not until the −2nd century that we can be certain that orpiment was even distinguished from other yellow pigments.[531] The first reference we have to the mining of arsenic sulphides (in this case realgar) dates only from the +4th century,[532] though orpiment is mentioned as a medicament in the *Shen Nung Pen-Tshao Ching* 神農本草經 (Classic of Pharmaceutics of the Heavenly Husbandman), a reference that could be as early as the −1st century.[533]

Most arsenical ores were excavated from shallow workings. 'The material which can be calcined to produce arsenic oxide looks like earth but is firmer; and resembles rocks, but is finer in size. It is obtained by digging a few *chhih* (a metre or two) beneath the earth.'[534] In Yunnan, however, orpiment outcrops tended to appear on the sides of mountains at some height above the water level and thus could be worked to greater depths than many of the outcrop mines in the area.[535]

Arsenic was a powerful poison widely used in Chinese agriculture as an insecticide and a parasiticide.[536] Calcining it was extremely dangerous. As Sung Ying-hsing 宋應星 stresses:[537]

> During the process of calcination, the workers must stand some 10 *chang* (about 30 m) upwind of the kiln; all grass and trees close to the downwind side of the kiln will die. Workers engaged in calcining arsenic must switch [to other work] after two years; otherwise all their hair will fall out.

Despite the danger, arsenic powder was freqently produced from arseno-pyrites in small primitive furnances by the population at large.[538] In later times at least, there

[530] Schafer (1955), p. 76. Other sources of smaller amounts of arsenic were arsenolite (the arsenic trioxide; de Mély (1896), p. 117; Vol. 5, pt. 2, p. 166) and, in Yunnan, the mineralogical rarity, native arsenic (Mathieu (1924), pp. 462–3).

[531] Schafer (1955), p. 75.

[532] *Ibid.*, p. 82; Vol. 3, p. 651. It could be that the Chinese had also learned to produce metallic arsenic by this time; Vol. 5, pt. 7, p. 114, fn. f.

[533] Schafer (1955), p. 77.

[534] *TKKW*, ch. 11, p. 205; Sun & Sun (1966), p. 210. According to Sung Ying-hsing, deposits of arsenic often (*chang* 常) were found beneath pools of turbid green water, but this sounds like an overgeneralisation from certain deposits with which he was familiar.

[535] Moore-Bennet (1915), p. 225.

[536] *TKKW*, ch. 11, p. 206; Sun & Sun (1966), p. 212; Bray (1984), p. 476. See also Vol. 3, pp. 651–2, which notes that arsenic was also used to accelerate the growth of silkworms, presumably because the silkworms were less susceptible to its poisonous effects than their viruses.

[537] *TKKW*, ch. 11, p. 206, my translation, assisted by Sun & Sun (1966), p. 212.

[538] Torgasheff (1930), p. 284.

were also operations of considerable size such as the works at Heng-yang 衡陽 in Hunan at the end of the Ming (+17th century) which produced almost 200 tonnes (presumably yearly).[539]

Arsenic was also used in smoke and other bombs,[540] and realgar provided yellow smoke as well as the brilliant white stars in fireworks displays.[541] Realgar was important in medical prescriptions and was even used to make medicine cups which provided a dose of arsenic from the dissolution of their inner face.[542] It served also to adulterate cinnabar.[543] Orpiment was frequently used as a pigment, realgar less so.[544] Finally, both were very important in alchemy.[545]

(ii) *Sulphur*

We know nothing about the very early use of sulphur in China. With the exception of one reference to 'brimstone' (*shih liu-huang* 石硫黃) dating perhaps to the −4th century and indicating only that it came from Han-chung 漢中 (present-day southern Shensi and northwestern Hupeh),[546] there appear to be no references to sulphur in surviving pre-Han texts (before −200).[547]

By the Han period, sulphur was apparently in wide use as a medicine; the *Shen Nung Pen-Tshao Ching* places it into the middle of the three categories into which it divided all drugs.[548] Its importance as a treatment for skin diseases, malnutrition and other ailments continued throughout the imperial period.[549] By Han times, sulphur was also important in alchemy where, along with mercury, it came to be widely viewed as one of the two most important substances.[550]

Other uses of sulphur in imperial times were in matches;[551] for fumigation;[552] as a whitening agent in baking;[553] as a bleach in the textile industry;[554] and, to be sure, as one of the three essential components of gunpowder.[555] Vitriol, a sulphur compound, was used as a mordant for dyeing cloth black (the colour of clothes for the common people) at least as early as the Han dynasty.[556]

Significant deposits of native sulphur are rare in China. Where they did exist, notably in Shantung[557] and Taiwan (see below), the sulphur bearing earth or rocks (Fig. 18) could be collected easily from surface or shallow deposits. In Yunnan, pure

539 *TKKW*, ch. 11, p. 205; Sun & Sun (1966), p. 210. Because any significant deposits of arseno-pyrites occur in association with lead, zinc and especially tin ores (cassiterite), most larger scale production of arsenic was carried on parallel with tin mining and smelting; Torgasheff (1930), p. 284.

540 Vol. 5, p. 7, pp. 2, 180, 187, 267. 541 Schafer (1955), p. 87. 542 *Ibid.*, pp. 83, 87.

543 *Ibid.*, p. 82. 544 *Ibid.*, p. 83. 545 See the many references in Vol. 5, pts. 2–4.

546 *Fan Tzu Chi Jan*, ch. *hsia*, p. 2b; Vol. 5, pt. 3, p. 14; Zhang Yunming (1986), p. 487.

547 Another early term for sulphur, dating from at least the +3rd century, was 'vitriol liquid' (*fan-shih yeh* 礬石液); Zhang Yunming (1986), p. 488. Zhang's 1986 article is an English rendering of Chang Yun-ming (*1982*).

548 For a discussion of the ideas behind this classification, see Unschuld (1986), pp. 23–5.

549 Vol. 5, pt. 2, p. 286; Zhang Yunming (1986), p. 487; de Mély (1896), pp. 246–7. 550 Vol. 5, pt. 4, p. 458.

551 Vol. 4, pt. 1, pp. 70–1. 552 Lin Chhao-chhi (*1969*), p. 115. 553 *Ibid.* 554 Hosie (1922), p. 170.

555 Sulphur at first lowers the ignition temperature of the mixture, then raises the temperature on combustion to the fusion point of saltpetre, and generally helps to increase the speed of combustion; Vol. 5, pt. 7, p. 111.

556 Zhang Yunming (1986), pp. 487–8.

557 Gan Zuyu *et al.* (1994), bk. I, col. 17; Zhang Yunming (1986), pp. 492–3. The Shantung deposits are low grade, averaging only about 10% sulphur; Li Yü-wei *et al.* (*1993*), p. 261.

Fig. 18. 'Stone' sulphur (*shih liu-huang*) from Kuang-chou (top) and 'earthy' sulphur (*thu liu-huang*) from Jung-chou (present-day Jung-hsien) (bottom). Probably an attempt to portray the two forms of elemental sulphur. The bottom illustration nicely conveys the hot spring type of environment in which sulphur is so often found. From the +13th century *Chhung Hsiu Cheng-Ho Pen Tshao*, ch. 4, p. 6b; reproduced in Unschuld (1986), p. 187.

sulphur was available as a deposit at the mouth of many hot springs.[558] But most Chinese sulphur over the last two millennia has been obtained from pyrites (metallic sulphides), especially troilite, pyrrhotite and marcasite.[559] Ancient terms for pyrites such as 'mineral outside coal' (*mei-than wai khuang-shih* 煤炭外礦石) and 'coal vitriol'

[558] Moore-Bennet (1915), p. 226.
[559] Dolbear *et al.* (1949), p. 1003. Simple heating is sufficient to derive sulphur from pyrites; Checkland (1967), p. 23.

(*mei-khuang shao-fan-shih* 煤礦燒礬石) suggest that the Chinese were early aware of the common association of pyrites with coal deposits.[560]

Pyrite deposits are widely distributed throughout China and sulphur mining thus was practised extensively.[561] Though the sulphur content of pyrite could be relatively high (Torgasheff gives a figure of 47.54 per cent for Honan[562]), the current average of all pyrite ores in China is only 17.79 per cent.[563] Also, the extent of individual deposits was generally limited.

A technique for extracting sulphur from pyrites seems to have been known by the Chinese at least by the +3rd century.[564] Sung Ying-hsing 宋應星 gives in his *TKKW* a good description and an illustration (Fig. 19) of the distillation process as it was in use in Kiangsi in the +17th century.[565] Zhang Yunming (Chang Yun-ming) estimates that, during the Chhing, between 200 and 400 tonnes of sulphur were being produced yearly from pyrites, using a variety of processes that culminated in 19th century furnaces that could handle a charge of about 100 tonnes.[566]

The only part of China that seems to have had extensive deposits of native or elemental sulphur, i.e., sulphur associated with fumaroles and solfataras (volcanic vents) *and* the transport conditions that made possible economic working of the deposits was Taiwan. The main sulphur deposits of Taiwan lie in the extreme north of the island, with easy access to the harbour at Keelung.[567] The first Chinese notices of sulphur as an important product of Taiwan date from the Sung and Yuan.[568] By the end of the Ming, the natives were capable of producing substantial amounts of sulphur for trade: in +1645, two Dutch traders managed to obtain some 100,000 *chin* 斤 (or about 65 tonnes) which they in turn sold for a substantial profit.[569]

Most of that sulphur was probably produced in a process whereby sulphurous earth or rocks impregnated with native sulphur were first collected in surface operations.[570] The earth or rocks were heated in pans or cauldrons to a temperature high enough to melt but not volatilise the sulphur. In this process, lighter impurities came to the surface in a frothy slag and could be skimmed off while heavier materials sank to the bottom. The sulphur could then be poured off and allowed to cool

560 Zhang Yunming (1986), pp. 488–9. Another term for pyrites was 'copper coal' (*thung-than* 銅碳).

561 See the maps in Zhang Yunming (1986), p. 490, fig. 1 and Li Yü-wei *et al.* (*1993*), p. 256. Also, Ting, V. K. & W. H. Wong (1921), p. 35; Torgasheff (1930), p. 370; Shockley (1904), p. 867.

562 Torgasheff (1930), p. 370. It is not stated on what this figure was based.

563 Li Yü-wei *et al.* (1993), p. 260. 564 Chang Yun-ming (*1982*), pp. 32–3.

565 *TKKW*, ch. 11, pp. 204–5, 213; Sun & Sun (1966), pp. 208–10. Chang Yun-ming (*1982*, pp. 34–5) discusses the process in detail. Actually, this primitive process was probably well on its way to being replaced by more advanced indirect distillation methods, devised perhaps as early as the Sung, that took advantage of the fact that sulphur could be made to condense more efficiently in receptacles below the furnace. Meng Nai-chhang (*1982*), pp. 582ff.; Zhang Yunming (1986), pp. 494–5. For similar European processes of the +16th, see Smith & Gnudi (1959), pp. 88–90; Hoover & Hoover (1912), pp. 578ff. Cremer (1913, pp. 47, 48) describes the process used early in this century in Szechwan.

566 Chang Yun-ming (1986), pp. 492–7. 567 Davidson (1903), pp. 495–6.

568 Chao Khuang-hua & Kuo Cheng-i (*1984*), p. 58; Lin Chhao-chhi (*1969*), p. 110.

569 Lin Chhao-chhi (*1969*), p. 104.

570 Actually, there was usually no other option. As Biringuccio noted for +16th century Europe: '[Sulphur] is excavated from open mines because if the miners should try to extract it in any other way they could not endure to stay inside the mines on account of the great heat and unendurable odour that it gives out.' Smith & Gnudi (1959), p. 88.

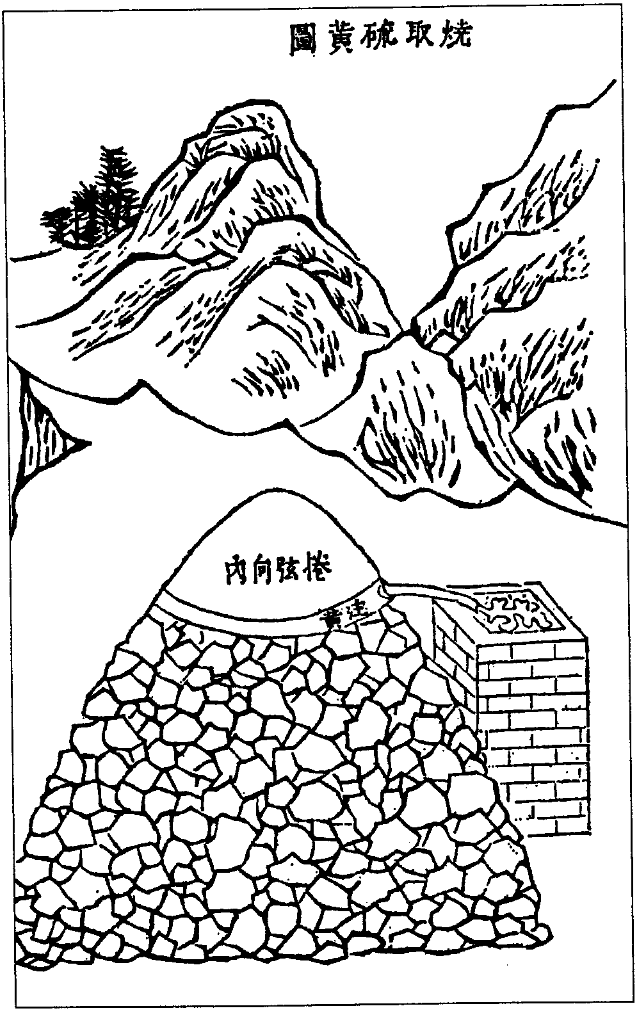


Fig. 19. Primitive furnace for slow burning of pyritic rocks in order to distill their sulphur, as illustrated in the *Thien Kung Khai Ku* 天工開物. The sulphur-containing rocks were mixed with coal briquettes in equal proportions (Sung Ying-hsing says 1,000 *chin* each) and the whole pile was then enclosed in packed earth to form a furnace (the earthen shell is not shown either in this illustration or in the later illustration clearly based upon it [*TKKW*, ch. 11, p. 213] which is aesthetically more pleasing but technologically no more informative). On top was added residue from previous firings and the whole was capped with an inverted porcelain bowl to serve as a still-head whose turned-under edge caught the sulphur condensation as it flowed down from the bowl and enabled it to flow out through an aperture into a small tank where it crystallised into sulphur. *TKKW*, ch. 11, pp. 204–5; Sun & Sun (1966), pp. 208–10.

Fig. 20. Extracting sulphur from sulphurous earth by means of an oil bath in Taiwan. Source unknown.

and solidify.[571] The problem with this process was that it was extremely wasteful and failed to recover much of the potentially available sulphur. Moreover, the sulphur it produced was relatively impure.[572]

To meet these problems, some miners on Taiwan had developed by the +17th century[573] an alternative process that seems to find no counterpart in other pre-industrial societies. This process was described in some detail by Yü Yung-ho 郁永河 in his *Phi Hai Chi Yu* 裨海紀遊 (Record of a Voyage Across the Small Sea). Yü journeyed into the mountains of northern Taiwan near present-day Pei-thou 北投 in the fifth month of +1697 and arranged for the production of a considerable amount of sulphur by this process.

According to Yü, sulphurous earth (which was abundant in this area[574]) was pounded into a powder and thoroughly dried. Some of the earth was then added into a cauldron of heated oil (probably rape-seed oil[575]) and stirred (Fig. 20). More oil and earth were then added alternately until the cauldron had been filled with 800–900 *chin* (a little over half a tonne) of earth and an appropriate amount of oil,

571 Davidson (1903), pp. 501–2. 572 *Ibid.*, p. 502.
573 Chao Khuang-hua & Kuo Cheng-i (*1984*), pp. 59–60.
574 Klaproth (1826–1828), Vol. 1, p. 328. 575 *Ibid.*, p. 60.

depending on the quality of the earth.[576] From time to time the workers would take out some of the liquid to test its fluidity (? *li thu phang chha chih* 瀝突旁察之) and adjust the mixture accordingly. Depending on the quality of the sulphurous earth, one cauldron could produce anywhere from several tens to as much as 400 or 500 *chin* of 'pure' sulphur (*ching-liu* 淨硫).[577]

Yü's description of the process raises a number of questions that have been elucidated in a study by Chao Khuang-hua and Kuo Cheng-i who have demonstrated by experiment with sulphurous sand the feasibility of this process. The low density of the ground sulphur powder and its affinity for oil cause it to form a suspension (emulsion) when mixed with the rape-seed oil. When the stirring process is interrupted, the heavier quartz sand sinks to the bottom of the cauldron. The oil/sulphur suspension can then be ladled into another cauldron where it is reheated. Because the melting point of sulphur (between 112.8 °C and about 120 °C) is far lower than the boiling point of the oil, the sulphur particles will first amalgamate in the oil and then, as the temperature of the oil rises, will liquefy and sink to the bottom of the cauldron. On cooling, the liquid sulphur at the bottom of the cauldron will solidify into a mass of quite pure sulphur which can be retrieved after first pouring off the oil. Virtually all of the oil can be recovered for re-use.[578]

As a vital component of gunpowder, sulphur drew considerable attention from Chinese governments. Already in the Northern Sung (+11th century), the government was faced with the dual problem of trying to maintain a monopoly on gunpowder weapons while at the same time assuring that large quantities of sulphur were available for its military needs. This led to prohibitions on trade with the Liao regime on its northern border in sulphur (and saltpetre)[579] as well as the importation of large amounts of sulphur. In +1084, for example, an imperial decree ordered the purchase of 500,000 *chin* (over 300 tonnes) of sulphur from Japan.[580] In the Southern Sung (+12th and +13th centuries), the official Pao Hui 包恢 (+1182 to +1268) submitted a memorial suggesting that trade with Japan in such 'useless' products as wood and shellfish be forbidden because it caused an outflow of bronze cash from China. He was willing, however, to allow trade in sulphur because it 'satisfied a military need' (*kung chün-hsu* 供軍需).[581]

During the Chhing (+1644 to 1911), there were repeated prohibitions on the private mining of sulphur.[582] Though the government's efforts to prohibit small-scale mining of sulphur could hardly have been very effective in most cases,[583] they may

576 Yü emphasises the importance of using just the right amount of oil but it is not clear just why this is so crucial.

577 *Phi Hai Chi Yü*, pp. 1a, 16a.

578 Chao Khuang-hua & Kuo Cheng-i (*1984*), p. 60. In the experiments of Chao and Kuo, approximately 80% of the sulphur present could be recovered by this process, the exact amount being determined in part by the fineness of the powder to which the sulphurous sand had been ground.

579 See above, Vol. 5, pt. 7, p. 126. 580 *HCP*, ch. 343, p. 6a; So (1982), pp. 146–7.

581 Shiba (*1968*), p. 226; Elvin (1970), pp. 94–5.

582 Lin Chhao-chhi (*1969*), pp. 111–14. By this time, the Ryukyus had become a further source of sulphur; Murray (1994), p. 99.

583 Lin Chhao-chhi (*1969*), pp. 113–14.

well help account for the relatively infrequent use of gunpowder in mining in the late imperial period.

(iii) *Abrasives*

The use of abrasives had begun already in Neolithic China, at least partly as a result of the Chinese fondness for jade (jadeite, nephrite) and similar rocks. These rocks, because of the toughness of their felted crystalline structure ('a seemingly haphazard arrangement of crosslaid skeins or filament bundles'[584]) could not be 'carved' in the normal sense but had to be shaped and decorated by means of abrasion, which meant the use of abrasive sands. At the same time, they also invited abrading because of the sensuous surfaces that could be obtained through polishing.

Quite possibly, the earliest experiments with abrading made use not of sands, as would be the case later, but of suitable rocks such as sandstone and schist.[585] By the Shang period, quartz powder was in use and Shang bronzes show evidence of several kinds of abrading: 'filing' away of mould joints, sharpening and polishing.[586]

Thereafter, progress in this area meant finding ever harder substances to serve as abrasives. It is interesting that, by the latter part of the −1st millennium (in the Warring States period), the Chinese frequently carved agate, a stone that is harder (7 on the Mohs scale) than any pure metal. It would just barely be abradable using quartz sand (hardness also 7) though the task would have been significantly easier with crushed garnet sand (hardness 7–8) or emery (crushed corundum; hardness 9). But there is no evidence for the use of garnet sand before the Thang[587] or of emery before the +12th or +13th centuries.[588] With all the placer mining that took place in China from early times, Chinese miners and craftsmen could be expected to be familiar with what sands served best for abrasive purposes, but it is somewhat surprising to see how long it apparently took before the idea arose to crush various kinds of stones and experiment to find out the abrasive qualities of their resulting sands.

Two other abrasive substances were also used in traditional China. The ferric oxide 'rouge' (*hung fen* 紅粉) is first referred to by Kuo Phu 郭璞 (c. +300) in his commentary to the *SHC*. At about the same time, we find what may be the first mention of diamonds (*chin kang* 金剛) in a Chinese work, and it has been suggested that they were at that time an import into China along with Buddhism.[589] In later times, most Chinese diamonds were found in Shantung where farmers often ploughed them up in their fields.[590] The diamond was never used as a gemstone by the Chinese but rather as the hardest abrasive they knew. In the Chhing, for example, the rough stones were regularly used in Shantung to drill holes in pieces of cracked porcelain so that they could then be wired back together[591] and in Canton for glass cutting.[592]

584 Keverne (1991), p. 53. 585 Leakey (1954), p. 139. 586 Barnard & Satō (1975), p. 71.
587 See above, Vol. 3, p. 668; Rawson & Ayers (1975), p. 7. 588 Rawson & Ayers (1975), p. 7.
589 Lu Hsueh-shan (*1984*), p. 5. For earlier works on diamonds in China, see Vol. 3, pp. 669–71.
590 Anon. (1898–1899), p. 642. 591 *Ibid.* 592 Gillan (1962), pp. 295–6.

(iv) *Potassium nitrate*

The most important nitrate in the pre-industrial Chinese economy was potassium nitrate (KNO_3), commonly known as saltpetre. The terminological problems surrounding potassium nitrate are very complex, and have been discussed in some detail previously.[593] For our purposes it is sufficient to note that the most common Chinese term to indicated potassium nitrate or saltpetre was *hsiao-shih* 消石 'solve-stone'. The first surviving mention of *hsiao-shih*, without any discussion of its properties, dates from the −4th century *Fan Tzu Chi Jan* 范子計然 (The Book of Master Chi, by Master Fan).[594] By the +1st or +2nd centuries, extraction of saltpetre was sufficiently widespread to give rise to a prohibition by the central government against saltpetre purification operations in the summer season.[595]

Deposits of potassium nitrate are found in at least half the provinces of China, though most of the major deposits occur in the north.[596] The deposits occur almost exclusively in the form of a white crust or powder on the surface of the ground. Bedded underground deposits seem to have been unknown in traditional times. Collecting the saltpetre was very easy. As Torgasheff describes it:[597]

> The present method of production is the same as in ancient times. When saltpeter is detected as a faint white veil-like patch of crystal formation, it is scraped off with spades, brooms, or shovels. It is mixed with water in brick tanks, and forms a brownish lye, which is boiled. The solution obtained, 'saltpeter water,' yields needlelike crystals of yellowish white crude saltpeter, which, after being refined, is sold in the form of small cakes.[598]

The two main uses of potassium nitrate in China were as a fertiliser and as a constituent of gunpowder.[599] Continuous cultivation over the centuries has led to mineral deficiencies (nitrogen, phosphorous and/or potassium) in nearly all the agricultural regions of China.[600] Although no chemical fertilisers were known in traditional China[601] potassium nitrate was, along with lime, one of the two mineral fertilisers widely used before this century.

From the government's point of view (always an important consideration when assessing developments in traditional China), potassium nitrate was primarily important at least over the last 1,000 years of the imperial period as a constituent in gunpowder. There is some evidence that the development of gunpowder weapons could have been slowed in some periods by a shortage of saltpetre. This might particularly have been true in the Southern Sung (+12th and +13th centuries) when north China, where the best deposits were located, was under the control of the non-Chinese Chin

593 Vol. 5, pt. 4, pp. 5, 179ff.; Vol. 5, pt. 7, pp. 94–6.

594 Also know as the *Chi Ni Tzu*; Vol. 5, pt. 7, p. 96.

595 *Ibid.*

596 Torgasheff (1930), pp. 380–1; Wei Chou-yuan (1946), p. 407. Sung Ying-hsing in his *TKKW* also lists Szechwan as one of the three most important sources in the +17th century; *TKKW*, ch. 15, pp. 267–8; Vol. 5, pt. 7, p. 103; Sun & Sun (1966), p. 269.

597 Torgasheff (1930), p. 381.

598 Compare the very similar account from the +973 *Khai Pao Pen Tshao* (Materia Medica of the Khai-Pao Reign-Period), quoted in *PTKM*, ch. 11, p. 54; trans. Vol. 5, pt. 7, p. 99. Vol. 5, pt. 7, pp. 102–6 has a great deal of information on processes used to purify saltpetre and criteria to test its quality.

599 It was also widely used along with borax in Chinese metallurgy, as in the refining of gold and silver; Hosie (1922), pp. 161, 163.

600 Bray (1984), pp. 25–6.

601 *Ibid.*, p. 298.

and then the Mongols.[602] Not much evidence has yet been discovered, however, about just what policies the government implemented to assure itself a steady and adequate supply.

Because of the ease with which it was obtained, potassium nitrate plays no significant rôle in the history of mining techniques in China. On the other hand, its identification was an important part of the difficult problem in traditional times of distinguishing various salts. Here, an important advance was the early recognition of the distinctive purple potassium flame of saltpetre. Such flame tests were an important part of the arsenal of Chinese mineral identification techniques that we shall discuss in some detail below ((*f*)(5)).

(v) *Building materials*

Shortages of wood in many parts especially of north China meant that stone, earth and clay had to substitute for wood in a host of uses ranging from structures (houses, walls) to a limestone slab over a creek where a board would have done just as well.[603] By the beginning of this century, Thomas Read could write that building materials were first among all types of 'mineral production', even though building stones were used only to a limited extent.[604] The main materials needed, apart from stone,[605] were the soil that from early times was tamped to form walls of all kinds,[606] the mud that was moulded and at first sun-baked but from Han on generally fired to produce the soft bricks out of which so many houses and walls were made, and the clays that formed the raw material for the fired tiles that made up the house roofs at least for those who could afford them. In addition, from the late Neolithic period at the latest, lime was used as a plaster in Chinese buildings.[607]

(vi) *Clays*

Apart from roof tiles, clay was also needed in large quantitites for making earthenware, stoneware and porcelain objects. Since clays vary considerably in their suitability for ceramic production, it is not surprising to find that, even as early as the Neolithic period, potters had learned to select the more appropriate clays and to avoid those that did not work well.[608] This included identifying those special clays, above all the kaolins (*kao-ling thu* 高嶺土), that made possible the hard white that became the forerunners of Chinese porcelains.[609]

602 Lu Gwei-djen *et al.* (1988), pp. 603–4. 603 Bain (1933), p. 7. 604 Read (1907), p. 1296.

605 Including the rubble stone that was regularly used, without binding material, to serve as the foundation for walls; Vol. 3, pt. 4, p. 39.

606 Vol. 3, pt. 4, pp. 38–40.

607 Sun & Sun (1966), p. 212, fn. 2; An Zhimin (1988), p. 757. Limestone, in its many forms such as marl (bog lime), chalk, travertine, dolomite and marble, was ubiquitous in China, frequently at shallow depths (Sun & Sun (1966), p. 202). Together with the lime derived from it by calcination, it came to be very widely used as a soil sweetener or fertiliser, a flux in iron smelting, an ingredient in smoke bombs, a pesticide, an ingredient in the processing of fibres in papermaking, a mortar and a waterproof sealant, as well as an adulterant and colourant of rice and flour.

608 Hsia Hsiang-jung *et al.* (*1980*), pp. 342–5; Cheng Te-khun (1974), p. 222.

609 Hsia Hsiang-jung *et al.* (*1980*), pp. 345–6. Kaolin also drew attention because it could serve as an antacid; see above, Vol. 3, p. 651. For 54 major kaolin production sites throughout China, see Ho Yueh-chiao & Chu Fu-hsi (*1986*), p. 207.

(5) Fuels

(i) *Coal*

(α) *Coal deposits in China*

China was the only ancient civilisation that possessed abundant coal resources.[610] Coal deposits of at least modest size are found in every province of China (Map 14 and Table 10).[611] Major deposits are concentrated, however, in two areas: in north China, centring on the province of Shansi, where one finds the world's largest deposit of coal, and in the southwest, including large parts of the provinces of Szechwan, Yunnan and Kweichow. Except for the great anthracite deposits of eastern Shansi, however, most of China's coal occurs in deposits that have undergone extensive faulting or intrusions of igneous rock. The resulting disturbance of the coal strata, though facilitating the discovery of coal,[612] has produced poor and discontinuous coal seams, especially in south China but also in much of the north.[613] An example is Wei-hsien 濰縣 in eastern Shantung. Because of extensive volcanic activity in the geological past, the coal deposits have been so greatly altered that it took Western mining engineers at the beginning of this century almost a year to find a continuous seam.[614]

Except when occurring at or close to the surface, irregular deposits require considerable dead work or excavation of enclosing materials in order to get at the coal.[615] This of course increases the cost of the coal although cost of coal at the minehead has usually been far less of a brake on consumption than the expense of transporting the coal to population and industrial centres.[616]

Extensive faulting also facilitates the seepage of water into mines. Even 'a little water causes a lot of trouble' in coal mining[617] but this problem was compounded in China by the fact that much of her coal lies associated with bedded limestone that frequently contains enormous reservoirs of water. Because of the extensive folding, these reservoirs are frequently breached in the process of mining.[618] In the worst cases, this can create serious dangers for the miners. The fear of water was vividly expressed by coalminers in Shansi at the beginning of this century who claimed that, underneath the nine or ten strata of coal that they had identified, lay 'water reaching to the sea; full of dragons and dangerous to disturb!'[619] At best, it has made water removal perhaps the biggest and most widespread problem in Chinese coal mining.

[610] Read (1939–1940), pp. 131, 133.

[611] For a detailed discussion of the geology and distribution of Chinese coal deposits, see Chhen Ping-fan (*1954*), pp. 31–83.

[612] Especially in the loess-covered plains of north China; Drake (1902), pp. 429–3.

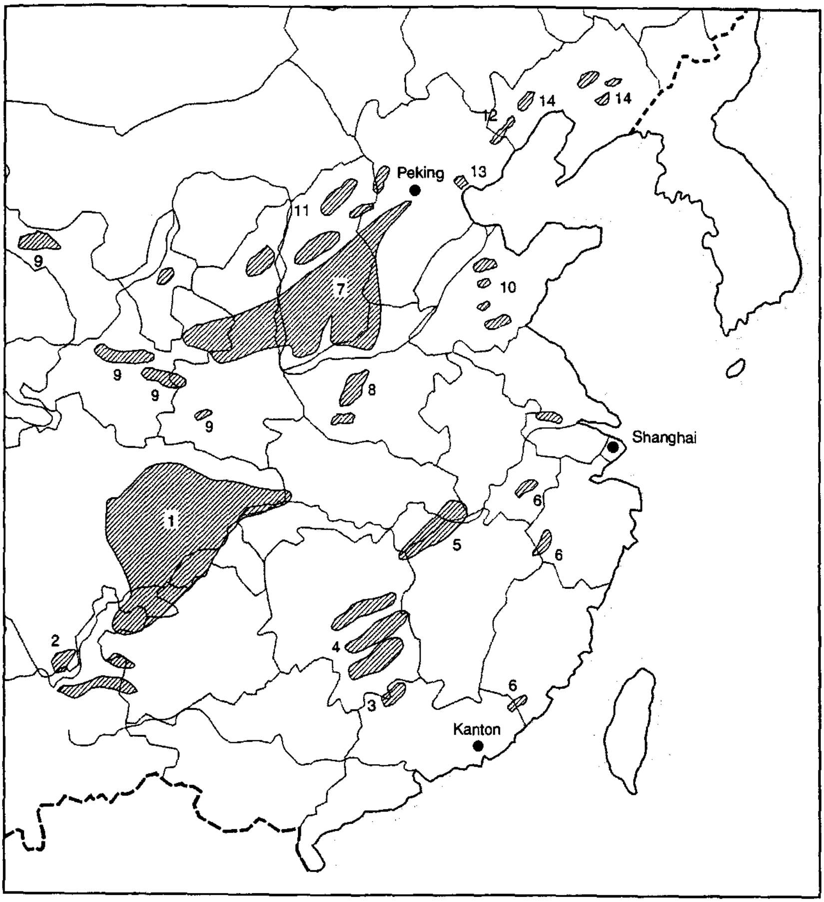
[613] von Richthofen (1872b), p. 8; von Richthofen (1871), p. 18; Bain (1933), pp. 48–9; Shimakura (1967).

[614] Anon. (1908), p. 170.

[615] Bain (1933), p. 64. Carlson has noted that the depth of coal mines in the famous Kaiping 開平 field was limited in part by the increasing likelihood of encountering at depth seams of limestone that were difficult to cut through; Carlson (1971), p. 9. For discussion of near-surface deposits or outcrops of coal, see (*f*)(1) and (*g*)(2).

[616] This is discussed further in (*e*)(5)(i)(ε) below. [617] di Villa (1919), p. 92.

[618] Bain (1933), p. 64. [619] Shockley (1904), p. 851.



Map 14. Major coal deposits of China as known in the mid-19th century. (1) Szechwan; (2) Yunnan; (3) Kwangtung; (4) South Hunan; (5) Central Hunan; (6) Fukien and Chekiang; (7) Shansi and Shensi; (8) Honan; (9) Kansu; (10) Shantung; (11) Northern Shansi; (12) Shih-men-tsai; (13) Khai-phing; (14) Smaller fields in Chih-li and Sheng-ching. Map by von Richthofen in Hochstetter (1876), reproduced in Wang Hongzhen *et al.* (1991), p. 97. Compare more detailed maps in Cressey (1955), p. 134; Geelan & Twitchett (1974), pp. xxx–xxxi; Ho Yueh chiao & Chu Fu-hsi (*1986*), p. 61.

Some of China's coal beds, especially in the north, are notable for their thickness. A striking example is the deposit at Fu-shun 撫順 just east of Shen-yang 沈陽 in Liaoning. There, seams over 200 m thick rank among the thickest seams to be found anywhere in the world.[620] In Shansi, the anthracite seams averaged a very workable

[620] Wang K. P. (1982), p. 134; Bain (1933), p. 65.

Table 10. *Coal reserves in China (as estimated between 1934 and 1945)*[a]

Province	Reserves, in millions of tonnes				
	Anthracite	Bituminous	Liginite	Total	Rank
Anhwei	60	300	—	360	24
Chahar	17	487	—	504	20
Chekiang	22	78	—	100	29
Fukien	147	6	—	153	28
Heilungkiang	—	5,000	3,980	8,980	4
Honan	4,455	3,309	—	7,764	5
Hopeh	975	2,088	2	3,065	9
Hunan	741	552	—	1,293	14
Hupeh	45	309	—	354	25
Jehol	—	4,714	—	4,714	7
Kansu	59	997	—	1,056	16
Kiangsi	271	420	9	700	18
Kiangsu	25	192	—	217	27
Kirin	—	5,581	478	6,059	6
Kwangsi	45	1,111	1	1,157	15
Kwangtung	59	274	—	333	26
Kweichow	822	1,696	—	2,518	11
Liaoning	36	2,606	—	2,642	10
Ningsia	173	284	—	457	22
Shansi	36,471	87,985	2,671	127,127	1
Shangtung	26	1,613	—	1,639	13
Shensi	750	71,200	—	71,950	2
Sikang	3	501	27	531	19
Sinkiang	—	31,980	—	31,980	3
Suiyuan	58	396	22	476	21
Szechwan	293	3,540	—	3,833	8
Taiwan	—	440	—	440	23
Tsinghai	240	584	—	824	17
Yunnan	77	1,539	694	2,310	12
TOTAL	45,870	229,782	7,884	283,536	

[a] Though these are modern estimates, the mining done in traditional times is unlikely to have modified significantly the relative importance of deposits in the different provinces.
From Cressey (1955), p. 137, citing Nelson Dickerman, 'Mineral Resources of China,' in *Foreign Minerals Survey*, II, No. 7 (1948), pp. 178 and 202. (Anthracite total is corrected from 25,870.) For a somewhat different estimate that suggests rather less dominance by Shansi and Shensi, cf. Wright (1984), p. 80, Table 26. Compare also Wang Hua-lung (*1960*), p. 60, Table 5.

thickness of about 7 m.[621] Although thick seams are generally desirable, they do pose special problems of providing adequate support for the excavations.

The modern classification of coals is an extremely complex topic but, in general, we can say that the two most useful and used coals are anthracite and bituminous

[621] Shockley (1904), p. 847; Read (1912), p. 14. Coal seams worked today in China average a little over 2 m; Wang K. P. (1982), p. 139.

coal.[622] Anthracite ('hard coal' or 'stone coal') has a high carbon content and little volatile matter; it burns with a clean flame.[623] Bituminous coal contains more tar and impurities, but many bituminous coals can be transformed into a cleaner fuel by coking, a process of roasting comparable to the process of making charcoal from wood.[624] Before 1949, between one-tenth and one-fifth of China's known reserves consisted of anthracite, about four-fifths bituminous coal.[625] A negligible proportion of low-grade lignite was also being mined.[626]

The earliest detailed Chinese classification of coals that has come down to us is provided by Sung Ying-hsing 宋應星 in the *TKKW* and serves as an excellent example of how, in the absence of modern chemical understanding, easily observed characteristics such as size, friability, and character of the flame had to serve, if inadequately, as a basis of classification. According to Sung,

There are three kinds of coal: 'bright coal' (*ming mei* 明煤), 'broken coal' (*sui mei* 碎煤), and 'coal dust' (*mo mei* 末煤).[627] The large pieces of bright coal are about the size of a one *tou* 斗 (c. 10 litres) measuring box ... Even without using a bellows, they can be ignited with a small amount of charcoal and will burn through a whole day and night without going out. The smaller fragments found with the large pieces can be mixed with clean brown earth and water, formed into briquettes, and burned as fuel. There are two kinds of broken coal ... That which burns with a high flame (*yen kao che* 炎高者) is called 'rice coal' (*fan than* 飯炭) and is used for cooking. That which burns with a low flame (*yen phing che* 炎平者) is called 'iron coal' (*thieh than* 鐵炭) and is used for smelting and forging. This coal is moistened with water before being placed in the furnace and it is essential to use a bellows to bring it up to red heat. Coal must be continuously added as it burns. Coal dust is like wheat [flour] and is called 'automatic wind' (*tzu lai feng* 自來風). It is mixed with mud and water to form a briquette. When placed in the furnace or stove and ignited, it is like bright coal in that it will continue burning for a complete day and night.[628] Half of this kind of briquette is used for cooking, half for smelting, calcination and the making of cinnabar by resublimation of mercury. As for burning stones to produce lime, as well as alum and sulphur, all three coals can be used.[629]

[622] Much less useful are peat and lignite which contain considerably more moisture and volatile materials and thus burn less effectively.

[623] Anthracite results when the original carbonaceous vegetative materials have been subjected to considerable heating; Whitten & Brooks (1972), pp. 87–8.

[624] The availability of extensive deposits of bituminous coal that could be processed into coke gave the Chinese an important alternative fuel for iron-producing blast furnaces when the decline in timber resources became serious in many parts of China during the Thang and Sung; cf. Section (*e*)(5)(i)(γ).

[625] Cf. Table 10. These figures, given in Cressey (1955), contradict his earlier statement (p. 134) that 'China's reserves fortunately include large amounts of anthracite – one-sixth of the total.' According to current estimates, bituminous coal constitutes over 70% if China's reserves, with anthracite and lignite each accounting for 12%; Li Yü-wei *et al.* (*1993*), p. 59.

[626] Couling (1917), p. 368.

[627] Shansi miners early in this century were still using a similar classification that divided coal into lumped, mixed and fine; Shockley (1904), p. 862.

[628] Actually, the briquettes tended to produce little heat and lasted for only a short period; Kovanko (1838), p. 212.

[629] *TKKW*, ch. 11, p. 202; translation drawing on Yabu'uchi (*1969*), pp. 219–20; Sun & Sun (1966), p. 205. Less interestingly, Sung's contemporary Tshui Hsien 崔銑, in his *Chang-te Chih* 彰德志, distinguishes two categories of coal, firm (*chien* 堅) and soft (*juan* 軟), the first referred to as *shih* 石, the second as *mei* 煤. Cited in Lü Tai-ming (*1986*), pp. 18, 189.

This classification coincides rather poorly with modern classifications of coal based mainly on carbon content and percentage of volatiles.[630] Thus, while 'bright coal' seems mainly to have been anthracite, the 'broken coal' probably included both bituminous coal (the 'rice coal' with its high flame) and anthracite (the 'iron coal' with its low flame).[631] The coal dust of course cannot be identified as either anthracite or bituminous coal on the basis of Sung's description but, given the predominance of bituminous coal in China and the fact that, in both north and south China, it is often very friable,[632] most of this coal dust must have been bituminous.

Not too much weight need be placed on the fact that Sung has nothing to say here about coke. In the well-forested south of China with which he was most familiar, there would have been little impetus to switch from charcoal to coke. In any case, as the Chinese did come to use coke increasingly for the smelting of iron and steel, they were fortunate in that there was no shortage of good coking coal in China.[633]

(β) *The earliest recognition and use of coal*

A remarkable archaeological discovery in 1973 established beyond doubt that Neolithic inhabitants of the Shen-yang 沈陽 area in northeast China around −4000 had begun carving ornaments from black lignite (jet or black amber), a kind of coal typically found intermixed with other varieties (Fig. 21).[634] Mining of coal could begin so early because much of China's coal is quite soft and could therefore be excavated by primitive digging implements (Fig. 22). By the Warring States period, this handicraft industry was flourishing over large areas of China, including Shansi, Honan, Sinkiang, Kansu and Szechwan, and it continued to do so through the Han and later.[635] It must have provided a not insignificant stimulus to the discovery, distinguishing and mining of coal.[636]

630 Whitten & Brooks (1972), pp. 87–8. As the wood that is the basis of coal decays, is buried and undergoes increasing pressure, its volatile constituents are increasingly lost while the carbon content increases. This makes possible the following classification of coals:

Type	% carbon	% volatiles
Peat	57	40.5
Lignite	70	29.6
Sub-bituminous	80	19.0
Bituminous	85	12.5
Anthracite	94	5.0

631 Hsia Hsiang-jung *et al.* (*1980*), p. 396. 632 Read (1912), pp. 11, 18.

633 Read (1912), p. 18. Such shortages have developed with the growth of the metallurgical industries since 1949; Wright (1984), pp. 17–18.

634 Anon. (*1984*), p. 68; Anon. (*1978c*); Anon. (*1979*); Hsia Hsiang-jung *et al.* (*1980*), pp. 388–9. Jet, a fossil wood that has been altered by heat or pressure, frequently preserves the grain of the wood. Because of its softness, it can be carved. It takes a high polish, and its high carbon content means it can be burnt. Cf. Rosenfield (1965), pp. 125–6. The Chinese were not alone in the early discovery of coal as a handicraft material. In central Europe during the Neolithic period, sapropelic coals (similar to lignite) were used for carving jewelery; Shepherd (1980), p. 232. 635 Lü Tai-ming (*1986*), pp. 33–7.

636 Anon. (*1984*), pp. 69–72; Lü Tai-ming (*1986*), p. 190. Various archaeological reports use a variety of terms to refer to the lignite used for carving: *mei ching* 煤精, *than ching* 炭精, *mei ken* 煤根, *than ken* 炭根, *mei yü* 煤玉 etc. For a discussion of these terms, see Anon. (*1984*), pp. 70–1.

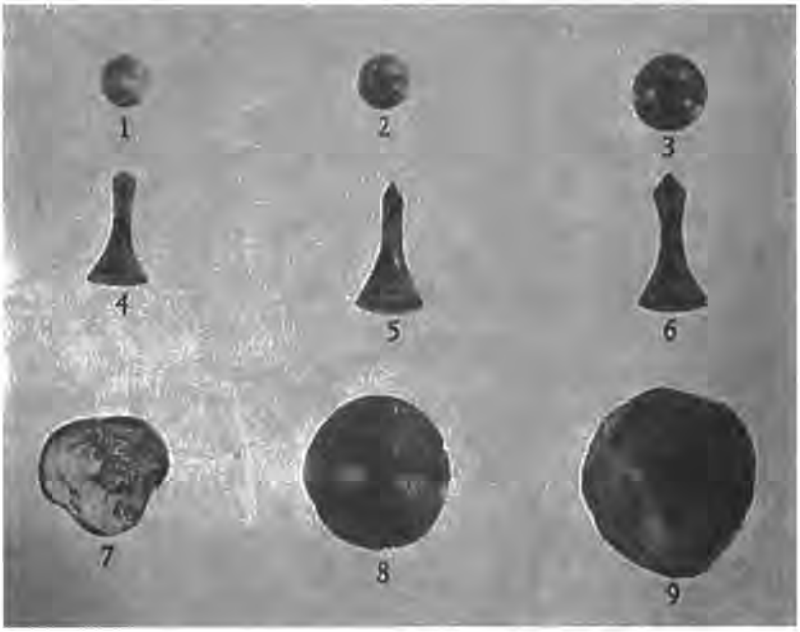


Fig. 21. Early examples of carved jet from Shen-yang, Liaoning. The round beads in the top row have diameters from one to two centimetres; the ear-piercing ornaments (?) in the middle are three to three-and-a-half centimetres in length; the bubble-like ornaments at the bottom have diameters ranging from two to five centimetres. Anon (*1978c*), pl. 1.

This raises the interesting question of the amount of time that elapsed between this recognition of coal as a distinctive material for producing handicraft products and the awareness that it could also be used as a fuel. As we shall see in a moment, the first hard evidence we have for coal as a fuel dates from the Han dynasty. Nevertheless, Wu Hsiao-yü makes a compelling case for the likelihood of such a use much earlier, suggesting that the Chinese would have had many opportunities to see coal outcrops set on fire either by lightning or by spontaneous combustion resulting from oxidation.[637] Moreover, since black lignite combusts rather easily, there would also be the possibility of accidental combustion of the carving material by sparks from hearth fires.[638] Even if the heating possibilities of coal had been recognised at an early date, there is little reason to expect that coal would have been used extensively for this purpose as long as supplies of firewood remained abundant.[639] Though all of this is conjectural, it does suggest a real possibility that evidence may yet be found

[637] Anon. (*1984*), p. 72. See also Lü Tai-ming (*1986*), pp. 3–4. Another possibility would be accidental ignition of outcrops by campfires; Vol. 5, pt. 4, p. 437, fn. f. Chao Chheng-tse and Lu Lien-chheng would even argue that, since all coals will burn while only a small proportion of coals can be carved, it would have been far easier for the Chinese to discover the heating capabilities of coal than that certain kinds of coal could be carved; Chao Chheng-tse & Lu Lien-chheng (1978); Hsia Hsiang-jung *et al.* (*1980*), p. 390.

[638] Chao Chheng-tse & Lu Lien-chheng (*1978*), p. 66.

[639] The Romans in England sometimes made use of coal but apparently only when wood was scarce and peat was either absent or hard to dig; Shepherd (1980), p. 232.

Fig. 22. Coal miner digging out the coal with a simple digging stick consisting of a long iron head mounted on a wooden handle. It would presumably be especially useful in coal mining since it could serve equally well as a crowbar to pry out the coal. Less appropriate would be the two lamps, drawn with great flair, but suggestive of the practices that have led to the death of many a Chinese coalminer. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 115, pl. 3. (Compare Fig. 58 and Fig. 62.)

to date China's, and therefore perhaps the world's, first use of coal as a fuel to well before the Han.[640]

References to coal in surviving texts sometimes escaped notice by earlier historians because they were couched in a changing and confusing terminology.[641] On the other hand, texts that could refer to charcoal or even quicklime have sometimes mistakenly been taken to provide clear evidence for the use of coal.[642] It now seems beyond doubt that coal was in use as a fuel both for industrial and household purposes no later than the final years of the Han and possibly considerably earlier.[643] It is much more difficult however to estimate how widely it was used at that time or even for many centuries afterward.[644] Most of the basic texts, which are none too informative, have been conveniently assembled and presented by Wang Chung-lo.[645] The most remarkable is a letter in which an official, Lu Yun 陸云, whose dates (+262 to +303) are almost the same as those of the Western Chin dynasty that unified China briefly after the division of the Three Kingdoms period, writes to his brother: 'One day I went up to San-thai 三臺 where His Excellency Tshao (*Tshao kung* 曹公) stored several hundreds of thousands of *chin* of coal (*shih mo* 石墨). It is said that when you burn this and then extinguish it, it can be reused for heating (*yun shao tzhu hsiao fu kho yung jan* 云燒此消复可用然). I do not know if you have seen this, brother, but I am now sending you two basketsful.'[646] Since 100,000 *chin* at that

[640] In this connection, we might note the claim that both the *Shih Chi* (Historical Records) of Ssu-ma Chhien and the *Lun Heng* (Discourses Weighed in the Balance) of Wang Chhung present, in essentially the same words, what may be the first record of a coal mine disaster in Chinese history. (Lü Tai-ming (*1986*), pp. 21–3, which conveniently photoreproduces the original texts.) The passage in the *Lun Heng* has been translated by Forke as follows: 'A younger brother of the Empress Dowager Tou 竇 [wife of Emperor Wen (r. –179 to –156)] and mother of Emperor Ching (r. –156 to –140), by the name of Kuang Kuo 廣國, was at the age of 4 or 5 years stolen from his poor family and sold. His people knew nothing of his whereabouts. More than ten times he was resold to other families, until he came to I-yang 宜陽. There he went into the hills to make coal (*tso than* 作炭) for his master. When it grew cold at night, over a hundred people lay down under the coal (*wo than hsia* 臥炭下). The charcoal collapsed and all were crushed to death except for Kuang Kuo, who managed to escape.' (Forke (1907), p. 179, slightly modified.) Forke's thus twice uses 'coal' to translate *than* although it seems actually to refer to the charcoal the men were producing. This interpretation is supported by a briefer version of the same story that appears in a later *chuan* (10) of the *Lun Heng* and says explicitly that the men were sleeping under 'piled-up coal/charcoal' (*chi than* 積炭); Pei-ching Ta-hsueh Li-shih Hsi (*1979*), p. 600; Forke (1911), p. 431. Lü Tai-ming, however, takes *tso than* to mean 'mine coal' and *wo than hsia* to mean that the men slept in a coal mine (pp. 21, 23). The latter reading seems inconsistent with the reference to 'piled-up coal/charcoal'. Moreover, this interpretation suggests coal mining on a scale very large for the –2nd century (a mine large enough to accommodate 100 sleeping miners). Lacking any other evidence for coal mining on a similar scale at this time, it is preferable to see this story not at all as a reference to coal mining but rather as a episode involving the making of charcoal.

[641] Chang Hung-chao (*1927*), pp. 201–5; Wang Chung-lo (*1956*); Chhen Chih (*1955*), p. 104; Lü Tai-ming (*1986*), p. 21. For similar terminological tangles in early English usage regarding coal, charcoal, coke, cinders, etc., cf. R. A. Mott's comments in Read (1939–1940), pp. 131–2.

[642] Wang Chung-lo (*1956a*), p. 24; Read (1939–1940), pp. 126–7.

[643] Chang Hung-chao (*1927*), pp. 203–4; Hsia Hsiang-jung *et al.* (*1980*), p. 390; Chao Chhing-yun *et al.* (*1985*), p. 106; Lü Tai-ming (*1986*), pp. 21–1. Hartwell even speculates that anthracite coal may have been used occasionally as early as the Warring States period in the smelting of iron by the crucible method; Hartwell (1966), p. 52.

[644] Wright (1984), p. 5; Wang Chung-lo (*1956a*), p. 24. The first surviving reference to coal in south China dates from the middle of the +5th century *Hou Han Shu*; Lü Tai-ming (*1986*), pp. 37–9.

[645] Wang Chung-lo (*1956a*), p. 24. See also Chang Hung-chao (*1927*), pp. 201–5; Read (1939–1940); Hsia Hsiang-jung *et al.* (*1980*), pp. 43, 390ff. For the first textual reference to the use of coal in smelting iron, in the 'Commentary on the Waterways Classic' (*Shui Ching Chu*), written in the +5th or +6th century, cf. Hua Jueming (1989), p. 2.

[646] *Thai-phing Yü Lan* ch. 605, emended by reversing positions of *hsiao* and *shao*, as in Hsia Hsiang-jung *et al.* (*1980*), 392. This seems clearly to be a reference to coke; my thanks to Graham Hollister-Short for pointing this out to me.

time would be equivalent to about 25 tonnes, Lu Yun is clearly talking about a substantial amount of coal. Thomas Read makes a persuasive case that this letter was written in the early years of the +4th century when the two brothers had gone to Szechwan to serve the prince of Chheng-tu 成都. Since they were natives of Kiangsu and seem to have seen much of south China, it is noteworthy that they apparently had not previously seen coal used a fuel.[647] There is also literary evidence (the first textual mention of the use of coal in iron-smelting) to suggest that, later in the same century, coal was used by the people of what is now Kucha (Khu-chhe 庫車) in the Tarim valley of Sinkiang in processing iron.[648]

Further evidence for some use by the +1st or +2nd century of coal in iron production may have been found in the excavations of the major Later Han iron production centre at Thieh-sheng-kou 鐵生溝 in Kung-hsien 鞏縣, Honan. Coal and coal briquettes are reported to have been discovered close to each of the 18 smelting furnaces at this site.[649] Coal briquettes are also reported at another Han iron production site in Honan, Ku-hsing chen 古滎鎮 near Cheng-chou 鄭州.[650] If the Chinese had already by this time learned to use coal dust by incorporating it into briquettes with a binding agent, this may indicate that significant use of coal dates back quite a bit earlier though there is no reason *a priori* why this might not have been a quite recent invention.

There is also other archaeological evidence that strengthens the case that the Chinese were using coal in the production (perhaps the smelting) of iron by about this time or just a little later.[651] There is always the temptation to posit a shortage of wood, perhaps because of deforestation, as a reason for the switch to coal in metallurgy.[652] But allowance must also be made for the possibility that coal may simply have been cheaper even where wood was plentiful. Thus, once the Chinese had developed techniques to cope with coal's impurities when using it as a fuel for smelting iron, demand for coal must have increased greatly in iron-making areas.[653]

By the beginning of the Sui dynasty, an official noted that wine could be warmed and meat cooked over coal, charcoal, bamboo, grass or hemp roots, and the taste would be different in each case.[654] Again, we have no evidence to indicate just how widely coal may have been used for cooking at this time.

647 Read (1939–1940), pp. 125–6. Lü Tai-ming (*1986*, p. 31) gives a slightly earlier dating.

648 Read (1939–1940), pp. 123–4; Hsia Hsiang-jung *et al.* (*1980*), pp. 393–4; Lü Tai-ming (*1986*), p. 30.

649 Hsia Hsiang-jung *et al.* (*1980*), p. 43; Lü Tai-ming (*1986*), pp. 27–8. But note that the members of the Chinese Archaeometallurgy Study Group argue that the coal was *not* used as fuel in the blast furnaces for smelting; Anon. (*1978d*). Cf. also Anon. (*1978b*), p. 98.

650 Hsia Hsiang-jung *et al.* (*1980*), pp. 391–2.

651 Lü Tai-ming (*1986*), pp. 26–30. Hua Jueming feels that the coal was used for roasting the iron ore to drive off impurities but was not used for the further process of smelting; Hua Jueming (1989), p. 2.

652 It is estimated, for example, that smelting of one tonne of cast iron required anywhere from four to eight tonnes of characoal; Lü Tai-ming (*1986*), p. 26.

653 If Donald Wagner is right and a major development in the post-Han Chinese iron industry was the development of effective small-scale techniques for producing iron (cf. (*e*)(2) above), including small blast furnances and crucible smelting, this must have encouraged the working of smaller coal deposits that could not have supported major iron production. But note another point made by Wagner (1985, p. 37), namely, that charcoal normally had an economic advantage over coal.

654 Wang Chung-lo (*1956a*), p. 24.

(γ) *The flourishing coal mining of the Sung*

Coal came into increasing use in China during the Northern and Southern dynasties, the Sui, and the Thang, i.e. from the +4th to the +10th centuries. It is possible that growing reliance on coal was encouraged by the increasing availability of better quality coal. Coal is unstable to some degree in the presence of the atmosphere or of meteoric (atmospheric) waters.[655] The result is that outcrop coal, the first coal that would have been used, is seldom very desirable for high burning temperatures.[656] The same would have been true for coal buried under only a slight overlay of porous soil or rock and thus still subject to the action of meteoric waters.[657] Unless we have a parallel here to early flint mining in Europe where the miners sometimes skipped the less good layers closer to the surface to mine the better flint at depth,[658] it would have only been after the first two kinds of deposits had been exhausted and the miners had had to turn to deposits deeper underground that they would have come to appreciate the full heating power of coal.[659]

Coal production underwent explosive growth in north China in the +11th century, especially in what are now the provinces of Shansi, Shensi, Honan and Kiangsu.[660] In this case, we know that much of the stimulus to greater production came from a shortage of timber on the north China plain.[661] By the latter part of the century, coal had become the exclusive fuel used in the well over 100,000 households in the capital, Khai-feng 開封.[662] Marco Polo, at the end of the +13th century, noted the ubiquitous use of coal throughout Cathay or north China especially in cooking stoves and for heating baths, either in public bathhouses or in the homes of the rich.[663] By this time, coal was also widely used for industrial purposes, such as firing ceramic

655 Lilley (1936), pp. 240–1.

656 von Richthofen (1872b), p. 18; Shepherd (1993), pp. 378–9. On the other hand, certain weathered coals were highly regarded for home heating because they gave off little or no odour and burned with a gentle heat (*chhi chhou phing chhi huo wen i jou* 其臭平其火文以柔); Lü Tai-ming (*1986*), p. 208, citing the +17th century *Yen Shan Tsa Chi*. Such gently burning coals were often referred to as 'dead' (*ssu* 死), as opposed to the more volatile 'lively' (*huo* 活) coals; *Ibid.*

657 At the beginning of this century, the rule of thumb among anthracite coal miners in southern and eastern Shansi was that one had to sink shafts to a depth of 50–70 m before obtaining top quality coal; Shockley (1900), p. 603. In some cases, where the best coal could not be mined because it lay below the water table, the Chinese had no choice but to make do with partially decomposed 'slack coal'; Hoover (1901–1902), pp. 426–7. See also Carlson (1971), p. 27; Williamson (1867), p. 65.

658 At Spiennes, Neolithic miners crossed 12 seams of lesser quality flint in order to work the very good quality flint at the 13th level; Shepherd (1980), p. 71.

659 The possibility of a parallel with early flint mining was suggested to me by Graham Hollister-Short. By the early Chhing, Sun Yen-chhüan notes in his *Yen Shan Tsa Chi* (Miscellaneous Jottings from Yen Shan) that the colouring of coal differs, with shallow layers being 'dull' (? *meng* 蒙) and deeper layers being lustrous (*ching* 晶; Lü Tai-ming (*1986*), pp. 189–90), a recognition that may have encouraged miners to go after the deeper and thus better strata of coal. By the beginning of the 20th century, 90% of China's coal was produced from underground mines rather than opencast workings; Wright (1984), p. 37. That high percentage was in large part, of course, the result of the establishment of modern coal mines with high production capacity.

660 Hartwell (1962), pp. 160–1; Hua Jueming (1989), p. 2; Chhi Hsia (*1987–1988*), Vol. 2, p. 548.

661 A condition that continued down to the end of the imperial period. See, for example, the 1740 memorial by Chao Kuo-lin 趙國麟, cited in Lü Tai-ming (*1986*), pp. 112–13.

662 Wang Chung-lo (*1956a*), p. 25; Kracke (1975), p. 66. Coal was also widely used in silkworm huts to maintain the warm temperatures necessary for the production of quality cocoons and for heating the water in which the cocoons were boiled to release the silk.

663 Polo (1961), pp. 207–8.

kilns.[664] Indeed, Hartwell hypothesises that premodern use of coal in China may actually have peaked in the second half of the +11th and first quarter of the +12th centuries.[665] This conjecture loses much of its persuasiveness, however, when one recalls that coal still was barely used throughout southern China, not only because of the more moderate climate but mainly because of the easy availability of wood and bamboo, greatly preferred fuels in traditional times.[666]

It is clear that, in the course of the Sung, coal and coke came to play an important role in iron smelting, although we do not have evidence to tell us just how important. Moreover, we know very little about how the technical problems of using coal and coke were solved.[667] The first archaeological evidence for the use of coke, as opposed to coal, in the smelting of iron comes from Hsin-hui 新會 in Kwangtung and dates only from the +12th century.[668] Coking was necessary before the commonly available bituminous coal could be used for many smelting operations.[669] Coke also has another advantage over coal: it burns hotter. As the early Chhing official and scholar Sung Yen-chhüan wrote in his *Yen Shan Tsa Chi* 顏山雜記 (Miscellaneous Jottings from Yen-shan): 'Calcined coal will become harder, so it is called *chiao* 礁 (coke). *Chiao* comes from coal, but it is more violent in burning than coal.'[670]

(δ) *Coal in late imperial China*

The size of the Chinese coal industry in the centuries following the Sung has been, as suggested above, the subject of some debate. Though it remains possible that per capita consumption for all China may never again before our own century have reached +11th century levels, absolute production remained high through the Ming and Chhing and many specific areas continued to enjoy an abundance of coal for both home and industrial use. One mining expert estimated early in this century that coal mining was five to ten times as 'important' as all the other mining in China combined.[671] In Shansi at that time, per capita coal consumption may have been as high as one quarter of a tonne or more yearly.[672] If so, that would be a significantly higher figure than that of Russia or Italy or Japan in the same period.[673] As had been

[664] Lü Tai-ming (*1986*), pp. 50, 58; Yü Ming-hsia (*1991*), pp. 17–19. The latter source makes a good case that the single mine (field?) at Pai-thu chen 白土鎮 near Hsu-chou 徐州 in Kiangsu was producing over 1,500 tonnes of coal yearly in the late +11th century.

[665] Hartwell (1962), p. 160.

[666] Chhi Hsia (*1987–1988*), Vol. 2, p. 548; Wang Chung-lo (*1956a*), p. 26; Read (1939–1940), p. 130.

[667] Hartwell (1962), pp. 159–62; Hartwell (1966), pp. 50–8. The earliest firm archaeological evidence for the use of coal in smelting iron is the high sulphur content of nine ingots of cast iron excavated at An-yang in Honan and dating from the Han; Hua Jueming (1989), p. 2.

[668] Hsia Hsiang-jung *et al.* (*1980*), p. 394. Knowledge of the process seems to have been lost later; Elvin (1975), p. 91.

[669] China had a great deal of bituminous coal that made very good coke; Hoover (1901–1902), p. 422. R. A. Mott discusses the difficulty of smelting iron with coal (Read (1939–1940), pp. 132–3) but he overstates the difficulty, probably influenced by the late discovery in England (only at the beginning of the +18th century) that coal could be used to smelt iron; Jensen & Bateman (1979), p. 386. It is possible to smelt iron with anthracite and with certain kinds of smokeless brown coals; Hsia Hsiang-jung *et al.* (*1980*), p. 391.

[670] Cited and translated in Hua Jueming (1989), p. 2. Translation slightly modified.

[671] di Villa (1919), pp. 48–9.

[672] Shockley (1904), pp. 842, 870. For the history of the coal industry in Shansi, see Hu Chung-kuei (*1988*).

the case at Khai-feng at the end of the +11th and beginning of the +12th centuries, Peking residents were highly dependent on coal and assuring its supply was a persistent concern of the central government.[674] It was during the Ming period that the production and use of coal first became widespread throughout south China.[675] In the +18th century, massive population growth increased the demand for fuel. Although timber resources were dissipated as greater numbers of people moved into the highlands of north and central China, certain of these areas such as southern Shensi offered abundant coal deposits to substitute for the increasingly scarce timber.[676] By the 19th century, China was probably producing several million tonnes of coal annually, some of it in pits as large as anything to be found in +17th century Europe.[677]

Much more important than the use of coal by households, however, was its use in industry, much of it rural and located near coal mines.[678] The major use in terms of tonnage was in the iron industry. Sung Ying-hsing 宋應星 in his *TKKW* estimates that, in the forging of iron objects, coal provided 70 per cent of the necessary fuel and charcoal only 30 per cent.[679] By the late imperial period, coal was also being used for calcining lime,[680] producing sulphur by calcination of pyrites,[681] boiling salt brine,[682] the fermenting of alcoholic beverages and the manufacture of ceramics, bricks (Fig. 23) and glass.[683] The (accidental) burning of underground seams of coal was a source of sal ammoniac (ammonium chloride) which was known by the Chinese perhaps as early as the later Han.[684] Also worth recalling is that it is in the Ming, with Li Shih-chen's association of lignite (*i* 瑿) with amber and his discussion of both in a chapter dealing with plants and plant materials instead of one dealing with minerals, that we find the first surviving written recognition that a kind of coal might have a plant origin.[685] In no way, however, could this idea have had any practical use for Chinese miners.

673 Bain (1933), p. 37. As always, however, the bulk of coal and the limited purchasing power of most Chinese made cheap transport, i.e. water transport, the key to its availability to people living any distance from the mines; Wang Chung-lo (*1956a*), p. 28.

674 Wang Chung-lo (*1956a*), p. 28; Wright (1984), p. 8. Their task was made relatively easier by the fact that Peking sits virtually astride a major coalfield. On the use of coal in homes, see the charming account of coal-fired khangs (炕, heated brick or tile sitting areas/beds) by the Jesuit Gabriel de Magalhaens; Vol. 4, pt. 3, p. 135.

675 *PTKM*, ch. 9, p. 95; Wang Chung-lo (*1956a*), p. 27; Hsia Hsiang-jung *et al.* (*1980*), p. 396.

676 Wright (1984), p. 8; Ho Ping-ti (1959), pp. 149–53, esp. pp. 151–3.

677 Wright (1984), pp. 5, 9. 678 *Ibid.*, p. 67.

679 *TKKW*, ch. 10, p. 191; Sun & Sun (1966), p. 189. Wright (1984, pp. 7–8) mistakenly takes this text to refer to the *smelting* of iron. Occasionally, in Yunnan, coal was used for the roasting and smelting of copper ore; Vogel & Theisen-Vogel (1991), p. 49.

680 *TKKW*, ch. 11, p. 210; Sun & Sun (1966), p. 200; W. Smith (1926), p. 74.

681 *TKKW*, ch. 11, p. 213; Sun & Sun (1966), pp. 208–10; Cremer (1913), pp. 47, 48.

682 Huc (1859), p. 190; Zelin (1988), p. 82.

683 Wright (1984), pp. 8, 64–6; Carlson (1971), p. 27; Smith (1926), p. 47. The main ceramics production centres of north China tended to be in coal mining areas (Wright (1984), p. 64), suggesting a significant dependence of this industry on coal.

684 Vol. 5, pt. 4, pp. 437ff.; Vol. 3, pp. 654–5.

685 Vol. 5, pt. 3, pp. 96–7, fn. cc. Actually, Li cites a text that suggests this recognition may even go back as far as the Three Kingdoms period (+3rd century).

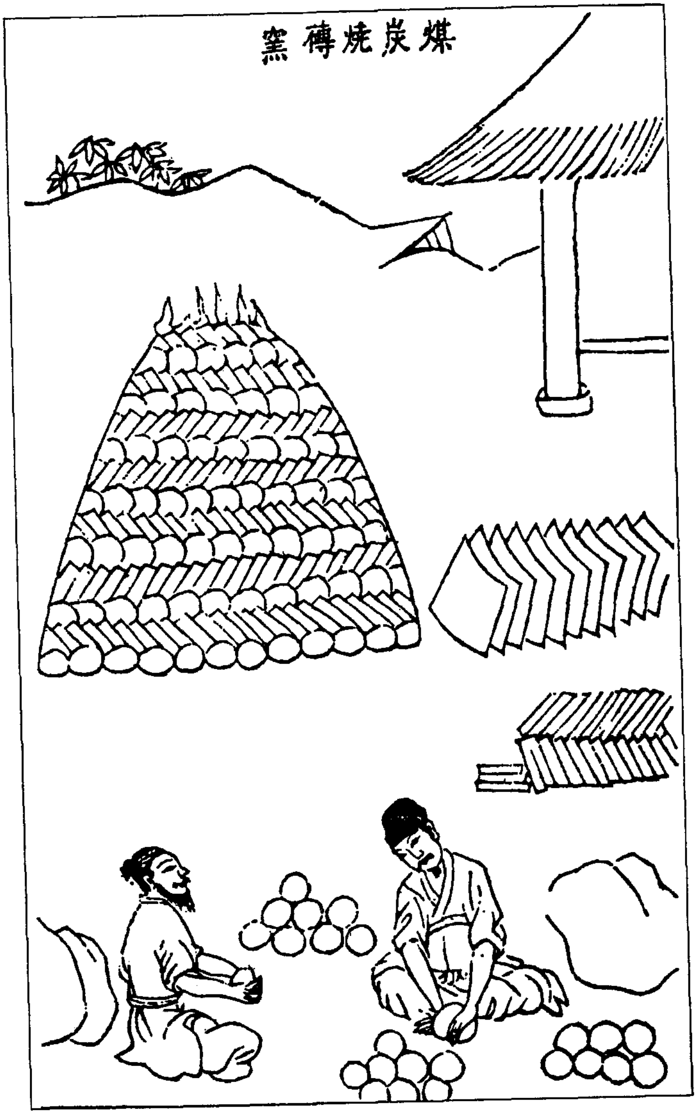


Fig. 23. An open-top coal-fired kiln for making bricks. The kiln is loaded with alternating layers of bricks and coal briquettes. Sun & Sun (1966), p. 141; compare *TKKW*, ch. 7, p. 146.

Table 11. *Approximate daily coal output per miner using native methods*[a]

Tonnes daily	Source	Comments
0.1	Torgasheff (1930a), p. 658.	Proposed as average for all native coal mines in China with production at most primitive mines as low as 0.05 tonnes per man/day (p. 518).
0.25	Junghann (1911), p. 16.	150 miners producing 40 tonnes daily at Tsching-Tsching (?) in Hopeh.
0.25	Wright (1984), p. 205, n. 21.	Miners in traditional mines at Kaiping in 1880s.
0.33	Elkins (1867), p. 248.	At Chai-thang, west of Peking, 40 miners producing 200 piculs or c. 13 tonnes per day.
0.4	Steward (1930), p. 888.	At Men-thou-kou west of Peking, each miner producing six loads per (normal) 12 hour shift, about 100 *chin* (catties) per load.
0.5	Anon (1861), p. 207.	Fayune coal fields, 60 miners producing 500 piculs or c. 30 tonnes per day.
<1.0	Sun (1967), p. 62.	Workers working a 24 hour shift at Chia-wang ming near Nanking in early 20th century.
1.0	Shockley (1903), p. 860.	Maximum production in a well-run native mine.

[a] These figures can be taken as suggestive only. One problem is that the authors usually do not make explicit whether the average per capita production figures include only the underground workers or hewers, or rather the total labour force.

(ε) *Limitations of traditional coal mining technology*

Compared with metal mining, coal mining posed fewer technological challenges. The frequent appearance of outcrops in easily accessible areas facilitated the finding of coal and its exploitation in surface workings or relatively shallow mines using the simplest of traditional methods.[686] The output per miner might be very low (cf. Table 11) but, given the low cost of labour, so too was the price at the pithead. Finally, coal was usable, with perhaps a bit of sorting, just as it came from the mine; it did not need further processing such as the smelting required to extract metals from their ores. The coal might be of very uneven and generally poor quality,[687] but that was usually of far less concern to consumers, whether household or industrial, than its price.

Thus the key condition limiting the development of coal mining in premodern China was extrinsic to the mining itself. Because of the costs of land transportation, the price of coal rose steeply the farther it was carried overland from the mine.

[686] An excellent discussion of these native methods is presented in Tezuka (*1943*). [687] Wright (1984), p. 52.

In late 19th century Hopeh, for example, coal sold 50 km away from the mine might cost five times as much as at the minehead.[688] At Tientsin in 1875, coal from Tse-chou 澤州 in Shansi that could be bought at the mine for $0.90 to $1.20 the tonne cost $14, in other words, as much as 15 times the mine price.[689] Much the same ratio prevailed for at least some of the coal on the Peking market.

Only where good water transportation was available did the situation change dramatically, making it economically feasible to ship coal even hundreds of kilometres. In the mid-19th century, at least 150,000 tonnes were shipped yearly (often on returning salt boats) from Lei-yang 耒陽 in southern Hunan up to Hankow 漢口 and then down the Yangtze as far as Shanghai 上海.[690] At Nan-yang fu 南陽府 in Honan, coal brought 1,300 km by water from Hunan sold for the same price as coal that had been mined 50 km away but transported to the city overland.[691] Because of the widely varying costs of water transportation and of various kinds of land transport (in ascending order of cost: cart, pack animal or wheelbarrow, coolie portage),[692] it is impossible to generalise with anything like precision about the relative costs of the two forms of transportation. In general, however, we can say that land transport typically was five to forty times as expensive as water transport.[693]

Since most areas of China, especially in the north, had no access to nearby water transport, coal usage was largely limited to areas quite close to the mines in the absence of special circumstances such as government concern to see that sufficient coal was available in the markets of the capital or where a sufficiently prosperous industry could afford a higher price for coal than the populace at large.[694] To some extent, the number of people benefiting from the availability of coal was augmented by the frugality displayed in its use. As S. Wells Williams noted: 'Anthracite is powdered and mixed with wet clay, earth, sawdust or dung, according to the exigencies of the case, in the proportion of about seven to one; the balls thus made are dried in the sun. The brick-beds (*khang* 炕) are effective means of warming the house, and the hand furnaces enable the poor to cook with these balls – aided by a little charcoal or kindlings – at a trifling expense. This form of consumption is common north of the Yellow River, and brings coal within reach of multitudes who otherwise would suffer and starve.'[695] Though this frugal usage might produce very great benefits in

688 *Ibid.*, p. 9. 689 Carlson (1971), p. 18.

690 Wright (1984), p. 9; Rowe (1984), p. 57. The trade was encouraged by the fact that Hunan produced good quality anthracite; Smith (1926), p. 48.

691 von Richthofen (1875), p. 23. 692 Wright (1984), pp. 43–4, 83.

693 von Richthofen (1875), p. 7; Brown & Wright (1981), p. 62. It is important to keep in mind when reading 19th century accounts of transportation conditions that the state of China's roads at that time had apparently seriously deteriorated when compared with the quality of earlier roads, for example, in the Sung; Huc (1859), pp. 128–9; Williamson (1867), pp. 52–4. Even in the best of times, however, nothing much in the way of 'roads' was likely to be found in the out-of-the-way areas where most mining was carried on; Read (1912), pp. 3–4.

694 Thus, it was not uncommon for more coal to be easily available than the market could absorb. As von Richthofen described Tse-chou fu (present-day Chin-chheng hsien 晉城縣), Shansi in 1870: 'Coal mines are of so little value, that legal conceptions, such as right, title and property, do not apply underground. Whoever wants to mine can do so. He makes a tunnel or sinks a shaft, at any place which is not occupied already by a mine, and produces as much anthracite as he can profitably sell . . .'; von Richthofen (1875), pp. 16–17.

695 Williams (1883), Vol. 1, p. 306. Briquettes were also used in southern China; cf. e.g. Cremer (1913), pp. 23, 34, 130.

human terms, it only reinforced the very limited character of the market for coal in most of China.

We have noted above that, in coal mining as in so much other underground mining, water was the most pervasive enemy of the miner. We shall discuss in more detail below the techniques developed and relied upon by the Chinese to rid mines of water. Here we might simply note that these techniques all fit effectively into one of two types: (1) various methods for lifting water out of the mines; and (2) excavating into a hillside an adit inclining more or less upwards so that water could flow downward out of the mine. Unfortunately, whatever methods were used, the traditional Chinese miners' ability to deal with large or even relatively small amounts of water was very limited, especially where, as in the mining of coal throughout China, the workings were typically small-scale and minimally capitalised. There was little chance of any significant expenditures for water management.[696] The result was that excessive water most often led to abandonment of mines. Nowhere was this more true than in coal mining where there was so often another deposit nearby waiting to be exploited.

(ii) *Petroleum and natural gas*

> The oil [in Szechwan brine wells] is reckoned by the Chinese as a necessary evil. They hate the touch or smell of it, and it is run out to soak back into the sands, with the exception of a small quantity used for lighting the works. *H. W. L. Way*[697]

Little need be said here about petroleum (*shih yu* 石油 'rock [mineral] oil'; *shih nao yu* 石腦油 'mineral-brain oil'; *shih chhi* 石漆 'stone lacquer'; *shih chih shui* 石脂水 'rock-fat liquid') in connection with mining in traditional China.[698] Since petroleum was present in many areas of China (e.g. Kansu, Szechwan, Shensi, Yunnan, and Kwangsi) either floating on bodies of water or seeping out of the ground, it is hardly surprising that the Chinese recognised it as a combustible substance as early as the Han.[699] In time, it came to be used for lighting, as a lubricant for cart axles and the

[696] Read (1912), p. 14. Boris Torgasheff, writing around (1930), suggested that even the smallest native coal mines typically had 20–30 miners with most having more than 100 and the largest 200 to 300; Torgasheff (1930a), p. 658. I doubt that coal mines were this large on the average in earlier periods when demand for coal was significantly less than it was in this century. Moreover, even in the 1920s and 1930s, there must have been large numbers of very small mines of the kind described by Cressey in the selection given at the front of this volume, by Raphael Pumpelly (1870, p. 292), by Maxwell Stewart (1930) and others. Pumpelly's comment that no mine in the Chai-thang 齋堂 area (now in the southwest corner of Pei-ching shih 北京市) in the 1860s could produce as much as 2,000 tonnes of coal per year was probably true of most Chinese coal mines at that time.

[697] Way (1916), p. 20.

[698] Interestingly, the term *shih yu*, first coined by Shen Kua in the +11th century (Shen Li-sheng (*1984*), pp. 9–12) but which only recently has become the universally used term for petroleum in China, has the same etymology as 'petroleum', which was coined in the Middle Ages from the Greek words for 'rock (*petros*)' and 'oil (*elaion*)'; Lucier (1991), p. 57. (For a convenient table, chronologically arranged, of the various terms used by the Chinese to designate petroleum, see Shen Li-sheng (*1984*), pp. 12–13.) For terms that have been used to designate natural gas, cf. Chang Hung-chao (*1927*), pp. 205ff; Wang Chung-lo (*1956*), p. 22; Tai I-hsuan (*1983*), pp. 66–9.

[699] For discussions of petroleum in China before the 19th century, cf. Vol. 3, pp. 608–9; Vol. 5, pt. 7, pp. 73ff.; Shen Li-sheng (*1984*); Wang Chung-lo (*1956*); Anon. (*1975a*); Tai I-hsuan (*1983*).

bearings of water-powered drop hammers, as a source of carbon for inksticks, and as a medical remedy for sores on humans and mange in animals.[700] Nevertheless, with one exception, there was never a large market for petroleum and limited demand could easily be met by collecting surface deposits.[701] That one exception seems to have occurred during the Sung dynasty when the government required considerable amounts of naphtha (distilled petroleum essentially the same as present-day petrol or gasoline) for its remarkably sophisticated flamethrowers.[702] This was the famous 'Greek fire' in the West, called by the Chinese 'fierce fire oil' (*meng huo yu* 孟火油). But even in this case, demand was hardly sufficient to trigger the emergence of a significant petroleum industry in China[703] though it is interesting to note that this period seems to have witnessed the first drilling of oil wells in China.[704]

Natural gas had a much greater but localised importance in Szechwan where, from at least the +3rd century, it was obtained from 'fiery wells' sunk alongside brine wells to a depth of up to 200 m.[705] The gas collected was used to boil salt brine. The obtaining and use of natural gas, however, is so intimately connected with the development of the salt industry that detailed discussion of it is reserved for Section 37.

[700] Vol. 3, p. 609; Hsia Hsiang-jung *et al.* (*1980*), p. 134. Abbé Huc relates two further uses: 'The Mandarins, by order of the Prince, sometimes buy thousands of jars of it, in order to calcine rocks under water, that render the navigation perilous. When a shipwreck takes place, the people make a kind of lamp of this oil, which they throw into the water near the spot; and then a diver, and oftener still a thief, goes down to search for any article of value that he can carry away, the subaqueous lamp lighting him perfectly.' Huc (1859), p. 190.

[701] A small amount was also obtained while drilling for salt brine in Szechwan; Anon. (1902), p. 893. According to the writer of this notice, no flowing oil well had been found in Szechwan up to that time.

[702] Vol. 5, pt. 7, pp. 81–91. It is not clear how early the Chinese practised such distillation, conceivably as early as the +7th century but certainly not later than the +10th century. Vol. 5, pt. 4, p. 162, fn. a; Vol. 5, pt. 7, pp. 92–4.

[703] Information on just how large the demand might have been has not survived, undoubtedly in part because this was national security information treated in something like the fashion of classified documents in modern governments; Vol. 5, pt. 7, pp. 92–4.

[704] Shen Li-sheng (*1984*), pp. 13–14. The first illustration of a Chinese oil well dates from +1762; see Shen Li-sheng (*1984*), pp. 14 and 16, figs. 1–2.

[705] Vogel (1991b); Liu Te-jen & Liu Chia-shou (*1982*). In the first half of the 19th century, Chinese drillers, still using native techniques, completed the first 1,000 metre natural gas well; Vogel (1993).

(*f*) PROSPECTING AND EXPLORATION

(1) Vein-like vs. Bedded Deposits

To appreciate the range of techniques employed by prospectors, it is essential to distinguish between vein-like ore deposits and bedded (stratiform, strata-bound) deposits (Fig. 24).[1] Ore deposits are typically sporadic and scarce. Because they are also usually small by comparison with their enclosing rock as well as difficult to recognise, their discovery can require a high degree of expertise. Bedded deposits, of which coal is by far the most important, are usually more widespread (at least within a given region).[2] They tend also to be larger and more regular than most ore deposits.[3] Where bedded deposits have not been seriously disturbed by geological forces, it is often relatively easy to find new deposits, at least in an area where the desired substance such as coal is known from previous mining to be present. In China, however, most of the coal deposits, except for the anthracite deposits of eastern Shansi, were anything but undisturbed and had undergone considerable faulting or intrusions of igneous rock.[4] Although this made the discovery of coal more difficult where the beds remained covered by significant overburden, it not infrequently aided prospectors by making the coal seams visible in outcrops.[5] A good example was noted by Joseph Edkins around the middle of the last century in his description of the situation at Chai-thang 齋堂, some 50 km west of Peking: 'Experienced miners go out to look for marks of coal in the limestone rock. They notice a wedge of coal with limestone on each side of it, or sandstone or slate on one side and limestone on the other. Observing its inclination they commence digging at a few tens of yards distant, where they are likely to meet the coal not too far from the surface by digging to it in a slanting direction.'[6] Bedded iron ore, too, was widely available and easy to find in Shansi; the rule of thumb for the miners of Yin-chheng in the southeast of the province was that, of ten shafts sunk, eight would find exploitable ore.[7]

Because finding vein-like deposits of metal and mineral ores posed the greater problems for prospectors, most of the following discussion will focus on the techniques used in this area of prospecting. Unfortunately, there is no aspect of mining

[1] Shepherd (1980), pp. 10–11; Torrens (1984), p. 89. Under 'vein-like' desposits we include also irregular intrusions of various kinds.

[2] For example: 'The only portion of Yunnan in which coal is not found is the extreme Southeast corner. Elsewhere in Szechwan, Kweichow, and Yunnan, it is impossible to travel 50 miles in any direction without finding either coal outcrops or workings . . .'; Moore-Bennet (1915), p. 217.

[3] Also very important in this context, though they are discussed separately in Section 37, were the salt brine deposits of Szechwan. See Vogel (1991d) and (1993).

[4] Shockley (1904), p. 848; Bain (1933), p. 64; Couling (1917), p. 368 and (*e*)(5)(i)(α) above.

[5] United Nations (1972), p. 41; Shockley (1904), p. 848.

[6] Edkins (1867), p. 246. It should be noted that this procedure leads the miners to begin excavating deeper, and therefore probably better quality, coal; cf. above Section (*e*)(5)(i)(γ).

[7] Shockley (1904), p. 849.

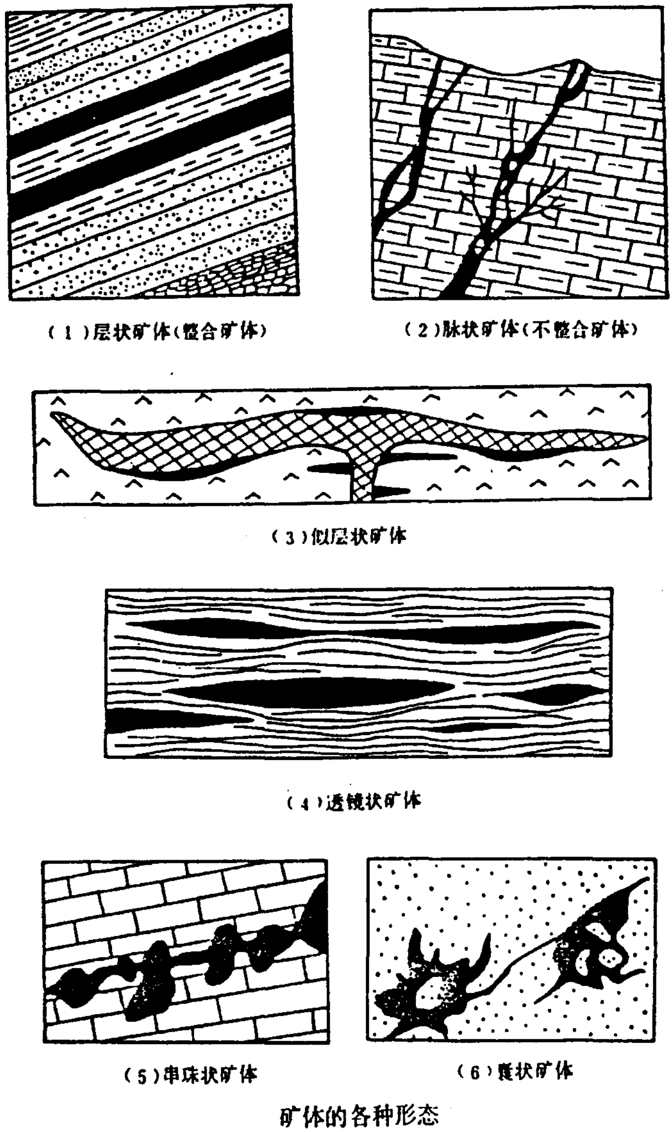


Fig. 24. Types of deposits: (1) Bedded deposit *tsheng-chuang khuang-thai* 層狀礦體 (conforming *cheng-ho khuang-thai* 整合礦體); (2) Vein deposit *mai-chuang khuang-thai* 脈狀礦體 (non-conforming *pu cheng-ho khuang-thai* 不整合礦體); (3) Quasi-bedded deposit *ssu khuang-chuang khuang-thai* 似礦狀礦體; (4) Lenticular deposit *thou-ching-chuang khuang-thai* 透鏡狀礦體; (5) 'Beaded' deposit *chhuan-zhu-zhuang khuang-thai* 串珠狀礦體; (6) 'Pocket' deposit *nang-chuang khuang-thai* 囊狀礦體. Ho Yueh-chiao & Chu Fu-hsi (*1986*), p. 4.

where it is more difficult to determine just what 'expertise' consisted of at any given time or place, no area where the gap was greater between the many who did and the few who wrote. Even if the miners had been capable of writing, they could not have described effectively in words the intuitive understanding that plays so great a rôle here.

(2) Accidental Discovery of Mineral Deposits

The discovery of deposits of minerals or other useful substances is by no means always dependent on conscious prospecting. Chance discoveries are a staple in the lore of most areas where substantial mining has been practised and they have frequently played a significant rôle in the development of mining.[8] China is no exception. Indeed, there is every reason to think that accident played a greater rôle than active prospecting in the discovery of most of China's deposits in traditional times, perhaps even greater than in other mining areas. Just as China's population and agriculture overwhelmingly were concentrated in approximately the eastern third of today's China (roughly the area east of the 100th meridian), it was also there that virtually all of China's mining took place. From very early times, much of this area was continuously settled with a dense population. The chances of accidental discovery of ore deposits were therefore correspondingly greater than would be true for more thinly populated mining areas. Agriculture itself made a significant contribution, with many outcrops being discovered by accident in the process of ploughing. Potters digging for clay could hardly avoid occasional discovery of ores. In north China, the digging of wells probably brought to light many a coal deposit at depth for which there was no outcrop indication.[9]

The *Chin Shih Pu Wu Chiu Shu Chüeh* 金石簿五九數訣 (Explanation of the Inventory of Metals and Minerals According to the Numbers Five and Nine) provides a nice example of how discoveries of mineral deposits were often made by those who were in no way engaged in prospecting as such. In +664, an Indian (Indo-scythian?) whose Chinese name was Chih Fa-lin 支法林 brought to China some Buddhist sutras to be translated from Sanskrit into Chinese. He was granted his request to visit the Wu-thai 五臺山 mountains to observe the Buddhist customs there. On the trip, he first noticed saltpetre in the Ling-shih 靈石 district of Fen-chou 汾州. On testing, however, it was found to be of poor quality compared to that of Wu-chhang 烏長 (Ludhiana, northwest India). Later in the trip, when his party came to Tse-chou 澤州, something in the terrain (though surely not the beautifully-treed mountain mentioned in the text) indicated to him the presence of saltpetre. The saltpetre was found and tested both by burning it (whereupon it produced the purple flame characteristic of potassium) and by using it successfully as a flux in smelting. Its properties were thus

[8] Hoover & Hoover (1912), p. 37, fn. 19; p. 36, fn. 16. Stoces (1958), Vol. 1, p. 18; Nef (1952), p. 437. Sinkankas (1970, p. 79) would even say: 'Up until the beginning of the 19th century, mineral deposits were found almost entirely by accident.' Something of an exaggeration, but perhaps not a very large one.

[9] Hommel (1937), p. 3.

found to be the same as those of the saltpetre from Wu-chhang 烏長 though it was a little softer.[10]

For an example of accidental discovery closer to the present, we have the story of how mining began in an area of Kwangsi some six hundred km up the West River (Hsi Chiang 西江) from Canton: 'Many years ago a native was on his way to the village store carrying a small load over his shoulders. As he passed down the valley, he sought, as is the Chinese custom, a stone with which to balance his load. Having picked up one of suitable size he adjusted his burden, doubling its weight, and went on to the store. A stranger, a Hunanese was at the store and as the farmer put down his burden, the stranger's eye was caught by the unusual colour and lustre of the stone. He opened a conversation with the farmer, who at first was reluctant to tell where he got it, but was finally persuaded to tell that and also to lead the Hunanese to the place where it was picked up. The stranger soon located the vein and returned home for his provincials who were to assist in its development. The natives, or Hakkas, soon became jealous and suspicious of the Hunanese, of their dark holes and fire furnaces on the mountainside, and tried to drive them away. A compromise was made and the Hakkas were persuaded to learn the business.'[11]

In some cases, even prospectors had little but chance to depend on. Many important ore deposits were found in places that could never have been predicted even by the best of modern, scientific prospecting techniques. To this day, the appearance of mica remains highly unpredictable.[12] The same can also be true of tin, which is still a challenging puzzle for mineralogists; as one Cornish mining engineer summed up the problem: 'Where it is, there it is.'[13] Silver lodes are also known for their unpredictability, displaying a tangled structure where random explorations stood about as good a chance of turning up a big strike as any other method.[14]

(3) Diligent and Skilful Prospecting vs. Weak Exploration[15]

Moving from accident to intent, we find that Chinese miners have shown themselves through the centuries to be diligent and skilful prospectors. Of course, with the limited techniques available to them (digging shallow exploratory shafts and

[10] *TT* 900, pp. 5b–6a; the passage is translated in Vol. 5, pt. 3, p. 139. A very similar discovery, important in the history of mining in Europe, occurred around +1462. A certain Giovanni da Castro was looking for mineral deposits in Italy. (He may have been accompanied by an astrologer, perhaps the equivalent here to a Chinese geomancer!) In the area of Tolfa, he recognised plants, especially holly, that he had previously seen in the alum rich mountains of Asia Minor. When white rocks in the area were tasted, they turned out to be salty. They were then boiled and produced alum, marking the first exploitation of this major alum deposit; Delumeau (1962), p. 20. (I am grateful to Graham Hollister-Short for drawing this incident to my attention.)

[11] Anon. (1905), p. 1186.

[12] A consequence is that even modern mica mining is mostly small-scale; Sloane & Sloane (1970), p. 46.

[13] Penhallurick (1986), pp. 1–2. Actually, there was in China a fairly strong association between tin deposits and biotite granite; Phan Chung-hsiang (*1951*), p. 140.

[14] Young (1970), p. 86.

[15] Though there is no universally agreed terminology to describe the finding and evaluation of mineable minerals and materials, a common usage refers to the earliest stage of looking for ore deposits as 'prospecting', to the further confirmation and determining the extent and nature of the deposit as 'exploration', and to the assessment of the commercial viability of the deposit as 'evaluation' (United Nations (1972), p. 35). Where useful, we

trenches, tracing float, panning), Chinese prospectors could not discover deposits other than those that lay close to the surface or that were at least suggested by some kind of surface indications (Fig. 25 and Fig. 26). These were limitations they shared with miners elsewhere. Nevertheless, the sheer scope of mining throughout Chinese history is in part testimony to vigorous and intelligent prospecting.

The map (Map 4) reproduced in our discussion of early copper mining indicates some 126 copper mining sites, and is far from exhaustive. As we have already noted, the *KT* mentions that some 467 mountains were already known by that time (perhaps as early as the −4th or −3rd century) to contain copper deposits.[16] Even that figure is dwarfed by the figure of 3,609 iron-producing mountains given in the same source. Hartwell has argued, overstating perhaps just a bit, that '[e]very single occurrence of iron ore worked in modern China or reported by 20th-century geological surveys had been located by Chinese prospectors by the end of the 11th century.'[17] The well-informed Thomas Read would extend that assessment to mining in general, arguing that most of the deposits capable of profitable exploitation given the existing technology had indeed been worked.[18]

The often desperate economic straits of the populace in China also encouraged miners to discover and exploit deposits that would have been ignored in many other parts of the world. Thus, by the 19th century, Chinese were mining gold in probably every province of the country, though few of the deposits paid well. As von Richthofen noted: 'The number of places in which gold occurs in the various hilly countries of Europe is probably greater, on an average, than an equal area's of China [*sic*]. But no notice is taken of them, because nobody could be induced there to wash gold with so little returns as are generally obtained in China . . .'[19] The very nature of mining as a wasting activity, that is, constantly using up the ores available, also encouraged continued prospecting in order to find new deposits to take the place of those that had ceased to pay.

Skill in finding and recognising mineral deposits, however, does not necessarily translate into an equal ability to determine the scale of a deposit, whether it is worth mining (i.e., evaluating the deposit), or how to go about the mining (i.e., exploration of the deposit). Failure to carry out exploration and evaluation can lead to egregious mining errors. One of the most striking examples in China was the attempt, as late as Ming times, to work the Ta-yeh 大冶 iron deposits on the central Yangtze as a copper mine, this despite the fact that the *average* copper content of the ore was only from 0.05 to 0.25 per cent![20] The same mistake was also made at Thung-kuan

shall adhere to that distinction. Another usage, however, would use 'exploration' to characterise the technologically highly sophisticated modern techniques used in the search for well-concealed minerals while reserving the term 'prospecting' for more traditional techniques; *Ibid.*, p. 36. Exploration in this sense is then followed by 'evaluation'; West (1978), pp. 106–8.

16 Cf. above, Section (*e*)(2).

17 Hartwell (1966), p. 33. We shall discuss below (in Section (*k*)) the rôle of mining experts in traditional China. These roving specialists must have done much to spread mining (including prospecting) knowledge and thus have been responsible for the discovery of many deposits that would otherwise have remained unrecognised.

18 Read (1920), pp. 298–9. See also Yang Li-hsin (*1988*), p. 182; Chou Wei-chien *et al.* (*1990*), p. 19.

19 von Richthofen (1872b), p. 75, fn.

20 Read (1912), pp. 30, 33; Read (1910a), p. 202.

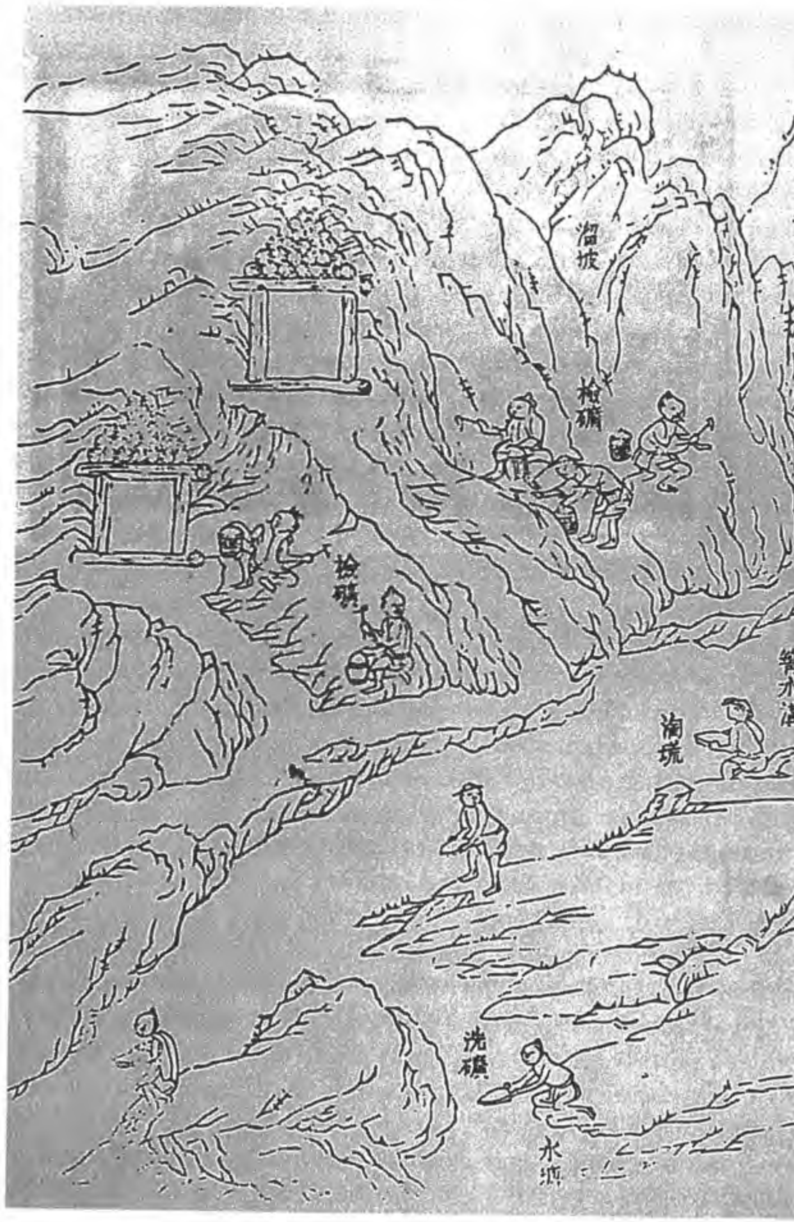


Fig. 25. Evaluating and washing ore at a 19th century mine in Yunnan. Wu Chhi-chün (*1845*), Illustrations, p. 4b. The miners in the upper part of the illustration are using small picks about the size of the average prospector's sampling pick (Draper (1931), p. 184) to dig out ore samples that will be washed and evaluated by the miners in the lower half of the illustration. For this task, which involved washing only small amounts of ore, the miners are using a wooden washing pan whose shape seems to resemble one kind of washing pan found at Thung-lü shan 銅綠山; cf. Fig. 30 (*a*).

Fig. 26. Someone with expertise (holding the umbrella) directing a miner prospecting for iron ore, perhaps the only existing illustration of this kind of reliance on an expert or specialist to guide prospecting efforts. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 119, pl. 1.

shan 銅官山 in Anhwei.[21] The error in both cases was more than likely due, as Wong [Ong] Wen-hao suggests, to localised concentrations of copper far in excess of the average concentration for the ore body as a whole, a fact that good exploration and evaluation would have revealed.

In a general way, Chinese miners were aware of the need for at least minimal exploration and evaluation to determine the extent and quality of ore deposits. Hence the pithy sayings such as the proverb cited in the introduction: 'For every mountain with a workable deposit, a thousand mountains have only veinlets (*i shan yu khuang, chhien shan yu yin* 一山有礦，千山有引).'[22]

Nevertheless, for Chinese miners as for miners in most pre-industrial societies, ease of access and working was usually of much greater concern than the ultimate richness of the deposits.[23] 'Efficient' or 'rational' exploitation of deposits tended to be neglected. Boris Torgasheff, commenting on gold mining operations in Manchuria well into this century, noted the reluctance of Chinese mining companies to engage in systematic exploration of deposits. As a result, '[i]t often happens, that the discovery of gold in one place results in an entirely wrong location of the works on the

[21] Wong Wen-hao (1920), p. 51.
[22] Yen Chung-phing (*1957*), p. 51. *Yin* 引 was regularly used to designate fibrous veinlets.
[23] Clark (1952), p. 186.

property in question, and the richest part of the placer escapes attention. Once the gold is discovered, the Chinese are anxious to begin the washing immediately on the spot discovered, and they can hardly be persuaded first to invest some money in prospecting [i.e., exploration and evaluation], to see what kind of works and from which end of the property they should start.'[24] If this was the practice of large companies that presumably could dispose of a certain amount of working capital, one can imagine the small likelihood that impoverished individual miners or small groups of miners could or would practise sound exploration of deposits. Moreover, the costs of exploration, whether in time, energy or capital, are much lower in the case of placers than for underground deposits. If anything, careful exploration must have been even less likely at underground workings.[25]

Mark Elvin has commented very astutely on the overly practical approach that often typified technology in China. He notes that 'experiment with its attendant errors and reflection with its consumption of time to little apparent profit were luxuries that were not easily afforded.'[26] Although mining in China was in many ways 'a technology apart' (see Section (*a*) above), there is no doubt that the kind of thinking Elvin describes was all too prevalent in Chinese mining, especially in prospecting and exploration. The failure to properly explore deposits before working them condemned the Chinese miners to a great deal of 'experiment with its attendant errors'. Only to some extent could Chinese miners compensate for shortchanging exploration by very skilful ore selection in the process of mining. Faced with a variety of ores of varying tenor (metallic content), Chinese miners typically relied on their practical experience to select the most promising ores. The archaeological remains of even early mines confirm that the miners must have had at least reasonably effective rules of thumb that enabled them to work only the best ores, leaving behind those that would pay only poorly.[27] Even today, goldminers in Kwangsi find the presence of a particularly smooth country rock (*hua shih* 滑石) bordering a gold vein to be a useful indicator that the vein is likely to be a good one.[28]

Nevertheless, lack of more systematic exploration led to many a mine being opened, perhaps at significant expense, only to be closed soon after because the economically workable ore gave out.[29] The absence of exploration activities can also be seen as one aspect of the generally unplanned character of Chinese mining. We

[24] Torgasheff (1930), p. 31. The same problem could occur with easily visible outcrops; the richest part of the deposit was not necessarily that which was easiest to find; Phan Chung-hsiang (*1951*), p. 141.

[25] Cf. Draper (1931, p. 182) commenting on underground work at the Ko-chiu tin mines: 'No ore is ever blocked out and it is unusual to see development work progress beyond the vicinity of a good working stope.'

[26] Elvin (1975), p. 108. [27] Chhueh Liang-chhing (*1978*), p. 103.

[28] Such *hua shih* was frequently pointed out to me by Professor Hu Chhu-yen 胡楚雁 during our visit to these mines in the summer of 1994.

[29] Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 628. It should be noted that the example given here from the Yunnan mines, where 137 of 175 mines opened between +1644 and 1838 had to be closed, does not by itself establish what is still a sound point because the authors do not tell us the average length of time a mine was in operation, whether it was really the exhaustion of good deposits that led to the closing of the mines (instead of, say, water problems that could not have been anticipated), etc. Over a period as long as two centuries, one would expect a high proportion of mines to be exhausted even if good techniques of exploration were employed in the early stages.

shall discuss in Section (*h*)(2) below the common practice of Chinese miners to follow carefully the windings of veins in order to minimise the amount of material to be excavated. The result was that, in addition to no plan from the start, there was also at any sizeable working little clear knowledge at later stages of the mining of just what had already been done. Thus, accidental breaking through to previous workings was not uncommon and could be dangerous, as when the earlier workings had been abandoned because of excessive water.[30]

(4) Prospecting in Practice

Many of the techniques used by traditional prospectors have not yet been and probably never will be put on a truly scientific basis. Even today, an experienced prospector or assayer can often look at a mineral specimen and pronounce it 'lively' or 'dead', indicating its degree of mineralisation.[31] Or, as one mining entrepreneur put it: 'There's a tremendous romance in this business. One person can look at a rock or a mountain and see one thing. When I look at a rock, I try to see inside and wonder if there is any gold hiding there.'[32] Boris Torgasheff remarked how, in Chekiang and Fukien, 'local experienced miners of the old school' were able to tell at a glance whether an alunite deposit was of sufficient tenor to be economically workable.[33] And if the texts cited by Lü Tai-ming and his colleagues are a fair reflection of thinking among coal miners, they had considerable confidence in their ability even to judge the likely depth and quality of prospective deposits.[34] Of course, the problem with such skills, especially insofar as they are intuitive, is that they vary widely in different individuals. One Western observer, writing in 1887, described what happened when he asked some natives of Shantung to bring him coal samples. He received three: a rotten basalt, a clay stained with manganese and an impure graphite.[35]

Regardless of its limitations, it was essentially intuition supplemented by experience on which the prospector relied in deciding where to look for minerals. His first step would probably be to try to get a 'feel' for the area by observing the terrain.[36] He would not know the geology behind the formation of igneous and sedimentary formations but easily observable differences in surface texture and colour intensity would tell him these were different kinds of rock. And if he had enough experience of the right kind, the prospector for metals would look for the acid (light) igneous

[30] Moller (1902–1903), p. 134. [31] Young (1970), p. 5.

[32] Interview with Arden L. Larson, president of Saratoga Mines, Inc., in *Business Trends* (Denver, Colorado), May–June (1984), p. 9.

[33] Torgasheff (1930), p. 388. [34] Lü Tai-ming (*1986*), pp. 188ff., esp. p. 192.

[35] Becher (1887). Hollister-Short suggests, given the extremely low level of skill these samples seem to reveal, that the Chinese were perhaps not trying too hard for the sake of this foreigner. (Personal communication.)

[36] Any good prospector had to develop 'an eye for the country'; United Nations (1972), p. 37. Prospectors looking for metal ores especially tended to pay attention to rugged areas of significant igneous activity with acidic or granitic rocks and to avoid areas with dense vegetation or with undisturbed sedimentary strata that could be easily recognised by their matte surface and pastel colouration. For a general discussion, cf. Young (1970), pp. 5–8. In Szechwan, land forms were the key determinant of where wells were sunk in order to obtain salt brine; Vogel (1991d), pp. 95–6.

rock that was glossy or vitreous from heat and perhaps showed some brilliant shades of colour that were one of his best indicators of mineralisation.[37] Contact metamorphic zones, especially where limestone met light-coloured igneous rocks such as granite and diorite, were very good prospecting environments.[38] They often revealed themselves by their general appearance and by the presence of certain rocks characteristically found in them, such as staurolite, kyanite, andalusite, cordierite, etc.[39] Gossans or masses of limonite or hematite could be a good clue to an underground ore deposit though experienced prospectors would know that this was not a conclusion to be drawn hastily since the weathered gossan material, through drainage or other means, could sometimes be displaced from its original location thus creating the deceptive 'false gossans'.[40] Chinese coal miners also relied on types of rocks as indicators of the presence or absence of coal, very often drawing on local experience. Thus, Sun Yen-chhüan noted in his *Yen Shan Tsa Chi* (Miscellaneous Jottings from Yen Shan) that shale (*shu shih* 數石) was often a good indicator of coal while limestone (*chhing shih* 青石) and sandstone (*sha shih* 砂石) were not.[41] It was also recognised that blackened rock and soil could be the result of a shallow coal deposit and, in Yunnan, a deep reddish shale was often a good indicator of a coal deposit.[42] A terrain where the earth had subsided could also be a sign of coal deposits.[43]

As metal miners accumulated an increasing store of experience, they would soon learn that the most promising prospects were usually to be found not in low country but in back country highlands.[44] Having arrived there, the Chinese prospector, perhaps in part influenced by what he knew about geomancy, would begin to look carefully at the forms of mountains.[45] Here he sought in the first instance rugged and jumbled and powerful formations (*shih chuang chhi hsiung* 勢壯氣雄) where water courses twisted and turned rather than running straight and placid. A section of a now lost but presumably Ming edition of the gazetteer of Lung Chhüan (*Lung-chhüan Hsien Chih* 龍泉縣志) cited in the provincial gazetteer (*Chhih Hsiu Che-chiang Thung Chih* 敕修浙江通志), reveals the kind of general knowledge on which virtually all prospectors relied: 'Ore deposits of the five metals appear (*sheng* 生) in places where the mountains are interlaced with rivers and streams, where the peaks are lofty and the ridges precipitous.'[46] In an effort to systematise these observations,

[37] Young (1970), p. 5. [38] Anon. (*1971*), pp. 101–2.

[39] Phan Chung-hsiang (*1951*), p. 138; Stoces (1958), Vol. 1, p. 38.

[40] Sinkankas (1970), pp. 206–7; Checkland (1967), p. 27. 'By oxidation the ferrous iron (Fe^{++}) is altered to the ferric (Fe^{+++}) state, thus yielding the reddish minerals, limonite and hematite.' Checkland (1967), p. 24.

[41] Cited in Lü Tai-ming (*1986*), p. 191. Of course, in some areas, sandstone was associated with coal deposits; von Richthofen (1875), p. 19.

[42] Lü Tai-ming (*1986*), p. 191; *TKKW*, ch. 11, p. 202; Sun & Sun (1966), pp. 95–6.

[43] Anon. (*1971*), p. 100. To be sure, this could also be a sign of previous mining, coal or otherwise, in the area or the corrosion of sulphide deposits underground; *Ibid.*, pp. 100–1.

[44] Young (1969), p. 132.

[45] As we noted above (Section (*c*)), prospectors and miners were undoubtedly at least as capable of acute and accurate observation of geological forms as Chinese painters whose renderings of geological structures can often be quite precisely identified.

[46] Chang Hung-chao (*1954*), p. 61; Yoshida (*1967*), pp. 239–40. Compare the similar text in *Shu Yuan Tsa Chi*, ch. 14, p. 8b.

however, arbitrary rules of thumb, probably as often as not misleading, were also introduced, such as the idea that long-lived deposits were found where the mountain facing the mountain to be worked was of equal height (*chhao tui chih shan te yü chu shan ping kao che, chhang shih yu chiu* 朝對之山得與主山並高者廠勢悠久).[47]

The prevalence of geomantic ideas in China also probably helped in at least a very general way to sensitise miners to certain characteristics of terrain and stimulated early generalisations about what kinds of terrain were or were not likely to offer good mining possibilities.[48] For example, the whole objective of the prospector was usually just the opposite of that of the geomancer. Where the geomancer was looking for sites in which the *yang* 陽 or male force of nature was concentrated, the prospector sought sites rich in the *yin* 陰 or female force, sites that instead of being 'exposed' promised hidden treasures within (*kuei yin chi yang, kuei tshang chi lu* 貴陰忌陽貴藏忌露).[49]

Meteorological indicators, especially clouds and vapours, also were carefully observed, though prospectors presumably varied considerably in the amount of weight they attached to them.[50]

After having found what he considered the right kind of terrain, the prospector then went searching for indications of the presence of mineral deposits.[51] These might be pieces of promising rock on hillsides (eluvial float) or bits of gold or other minerals in current or former stream beds (alluvial or placer deposits), as we have discussed above (cf. Section (*d*)(2)(ii)). Or perhaps one or more actual outcrops might be visible and invite investigation.[52] Quartz, for example, often signalled the presence of gold, silver, copper, tin, lead or zinc.[53] Sung Ying-hsing 宋應星 speaks of turgid green water as often being found above deposits of arsenic ores.[54] Prospectors would also be on the alert for 'blossom', the colour that metallic salts sometimes painted on an outcrop: brown to yellow for iron; blue and green for copper; light

[47] *Thung Cheng Chhüan Shu*, cited in Wu Chhi-chün (*1845*), ch. 1, p. 38a.

[48] At the same time, geomancers had their own reasons for making use of what prospectors and miners had discovered; see Yang Wen-heng (*1992*), p. 374.

[49] Wu Chhi-chün (*1845*) ch. 1, p. 38b; Yen Chung-phing (*1957*), p. 50; Wang Hongzhen (Wang Hung-chen) *et al.* (1991), p. 10. Compare, however, the widely accepted tradition of the discovery of the great Ko-chiu tin deposits which were first made at a place that a geomancer, with none too great a specificity, had earlier predicted was capable of bringing riches to the whole area; Su Ju-chiang (*1942*), p. 15.

[50] Yen Chung-phing (*1957*), p. 50. Edward Schafer (1955a, pp. 265–7) notes that mica was thought to be 'the veritable womb from which clouds were born'. That this was really a useful clue for prospectors 'who might dig, with reasonable hope of success, at some craggy spot above which the clouds were seen to rise' is open to question.

[51] Experienced prospectors also knew, at least intuitively, that prospecting often went better on sunny days since clouds significantly impair the ability to detect 'float'; Young (1970), p. 6. As John Sinkankas (1970, p. 140) points out, '. . . most mineral deposits do not advertise themselves except by very small signs which take a keen eye to discern.'

[52] Wu Chhi-chün (*1845*), ch. 1, p. 38a. The most commonly used term for outcrop was *miao* 苗 with an original meaning of 'seedling' or 'sprout' (another reflection of the basically agricultural perspective of the Chinese miners.) *Miao* was also used sometimes in a more general sense of any kind of indicator of the presence of minerals, including plants. (Vol. 3, p. 675.) *Huan* 槶 could also be used to designate outcrops though it sometimes meant the deeper vein; Wu Chhi-chün (*1845*), ch. 1, pp. 2a–b; Table 5 above.

[53] Anon. (*1971*), p. 102.

[54] *TKKW*, ch. 11, p. 205; Sun & Sun (1966), pp. 210, 212. For other examples of mineral deposits indicated by coloured waters, see Anon. (*1971*), pp. 99–100.

yellow for lead; rusty for some gold-bearing quartzites; and the dingy yellow or greenish white of silver 'glance'.[55] A good indicator of copper deposits, as we have seen, was the 'cap' or gossan of oxidised iron ore left after the highly soluble copper minerals had been leached out.[56] In the case of coal, as we also noted above, deposits with only a thin overburden might reveal their presence by imparting a dark colour to the soil.[57] Blossom could be especially helpful for discovering mineral outcrops since they are often not very noticeable. As Arthur Raistrick explains: 'Mineral veins are normally very narrow fissure deposits, nearly vertical and of a lateral extent that may be a few hundred yards up to a few miles. Their outcrop at the surface, therefore, is a long narrow ribbon, a few feet wide, needing considerable skill and sustained search for its discovery.'[58]

At some point, Chinese propectors discovered that it was possible to find hidden outcrops by tracing eluvial or alluvial deposits back to the outcrops from which they derived.[59] We are, however, quite in the dark as to when or under what circumstances this discovery might have been made.[60] Sung Ying-hsing 宋應星 in his *TKKW* has a passage that hints at how it might have occurred accidentally: 'The inhabitants of Nan-tan recover the tin ore from the river by first working from the south northward, and then from the north southward alternately at ten-day intervals. . . . Panned in this way, the ore supply will continue without exhaustion [!].'[61] If such a practice was at all common, it would almost certainly have led in some cases to the discovery of the outcrop from which the placer metal derived. On the other hand, this technique could well have been discovered rather late[62] since it is far less dependable than one might expect. Because weathering and erosion over a long enough time can produce quite rich concentrations of gold or other minerals even from insignificant veinlets, a rich eluvial and alluvial deposit is no certain indication of the existence of an important outcrop. Alluvial gold has frequently been mined successfully in districts where there were no veins or lodes worth exploiting.[63] One wonders if there is not perhaps a hint of the frustrations of miners who failed to find their expected outcrop in the statement of Chou Chhü-fei of the Sung in his 'Information on What is Beyond the Passes' (*Ling Wai Tai Ta* 嶺外代答) that: 'Gold does not come from ores but naturally congeals in sandy soil (*fan chin pu tzu khuang chhu tzu jan jung chieh yü sha thu chih chung* 凡金不自礦出自然融結於沙土之中).'[64]

[55] Young (1970), p. 20. Cf. also Lung Tshun Ni (1986), p. 119. [56] See above, Section (*d*)(2)(ii).

[57] di Villa (1919), p. 57. [58] Raistrick (1972), p. 20.

[59] In the case of eluvial 'float', rough and angular rocks were a good sign of a relatively nearby source since they had not undergone the smoothing abrasion that would have occurred had they travelled some distance; Young (1969), p. 126.

[60] Cf. Fig. 7(*b*). For a description of this technique, see Pearl (1973), pp. 109–10.

[61] *TKKW* 14, p. 241; Sun & Sun (1966), p. 251.

[62] The ancient Greeks were apparently unaware of it; Healy (1978), p. 71. [63] Rickard (1932), p. 93.

[64] *LWTT* ch. 7, p. 10a; Netolitzky (1977), p. 128. See also Yoshida (*1967*), p. 237 and compare the legend told of the early miners in California: lacking experience with anything except placer gold, they were puzzled when they first became aware of vein gold how the gold from the placers could have migrated to form these troublesome veins of solid rock! Paul (1963), p. 30.

In an area of proven mineral deposits, it might be worthwhile for prospectors to dig shallow trenches and shafts in an effort to find deposits that did not reveal themselves on the surface. The presence at Thung-lü shan 銅綠山 of extremely narrow vertical shafts (less than a half metre square), many of them off by themselves in places where no extensive mining was carried on, has been interpreted by Chinese archaeologists to indicate that they were dug for prospecting purposes.[65] Within the Thung-lü shan workings themselves, shallow vertical shafts descending from drifts have also been interpreted as having perhaps been exploratory shafts.[66]

Prospecting trenches were but a short step away from seeking or exploratory adits, which also brought the prospecting underground. By contrast, there was little recourse to prospecting by means of borehole drilling in traditional Chinese mining. This might seem at first surprising, given the broad experience with wells and even underground canals for irrigation in north China.[67] Moreover, the Chinese in the +11th century discovered deep drilling as a means of obtaining salt brine in Szechwan. At that time, narrow shafts lined with bamboo pipes were sunk to depths of more than 100 m. In the 19th century, a borehole salt well (the Hsin-hai well) was ten times as deep.[68]

This drilling capacity did not, however, necessarily translate into effective borehole drilling for prospecting purposes. With percussion drilling for water or salt brine, it made no difference if the extracted material was fragmented, crushed, or in a pulp. But such material was very difficult to assess for prospecting purposes. Indeed, it was not until the Irish mining engineer, James Ryan, invented at the beginning of the 19th century a device that worked on the principle of the trepanning saw and made possible the cutting of true cores that could be recovered in proper sequence from the borehole that borehole drilling acquired the potential to serve as a truly effective tool for the prospector.[69] Such a tool was never available to traditional Chinese prospectors.[70] Given the unreliable results that would typically have been obtained from more primitive forms of borehole drilling (especially when applied to China's irregular deposits (Fig. 27)), potential problems such as the possible flooding of adjacents mines with water introduced from the surface,[71] as well as a

[65] Yang Yung-kuang *et al.* (*1980–1981*), p. 86. It is sometimes difficult to imagine how such shafts could be entered, but they were. An unidentified but obviously first-hand observer of Shansi iron and coal mines early in this century comments on 'small shafts, seldom more than 14 in. in maximum diameter, and usually just large enough to allow a man to go down'; Anon. (1910), p. 761. Presumably the miners were lowered by a rope to the working level where the galleries would have had to be a least somewhat larger. An interesting contrast is provided by the anthracite coal mines in the same area. There the shafts were typically 2–2.5 m in diameter; *Ibid.*

[66] Hsia Nai & Yin Weizhang (1982), p. 38. [67] Cf. above, Vol. 4, part 3, pp. 257–8; 333–5.

[68] Vogel (1991c), pp. 84–90; Vogel (1993). It is from the famous literatus, official and poet, Su Shih 蘇軾 (+1036 to +1101), that we learn that wells no wider than a drinking bowl could be sunk to depths of 120 m or more; Vogel (1993), p. 119.

[69] Torrens (1984), pp. 90–1. Interestingly, the notoriously conservative British coal mining community was very slow to appreciate the potential of the new device.

[70] John Nef's description of the limits of the very crude boring rods available to English coal miners in the +17th century probably applies in a general way to the results available to Chinese miners before this century; Nef (1932), Vol. 1, p. 353.

[71] Galloway (1882), p. 60.

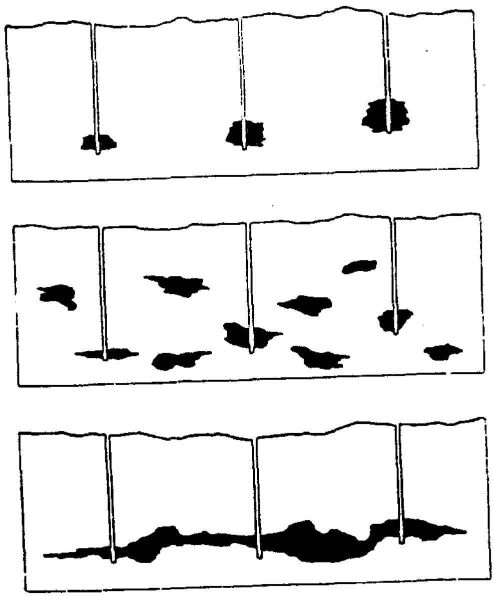


Fig. 27. Three possible interpretations of the same borehole drilling results. Stočes (1958), Vol. 2, p. 42.

ready supply of cheap labour that made prospecting and exploration by means of trenches or shafts economical, the Chinese not unreasonably opted for the latter method.[72]

(i) *Indirect aids in the search for ore deposits*

In the absence of surface indications of deposits or a history of successful mining in an area, Chinese prospectors often had to read between the lines as it were, and be alert for indirect indications of deposits.

[72] There were exceptions. At least as early as the first part of the 19th century, Chinese tin miners in Malaysia consistently used drilling as a prospecting technique; Wong Lin Ken (1965), p. 47, citing John Crawford writing in 1820. It is extremely unlikely that the Chinese were here adapting a Malay practice since Malay mining techniques lagged far behind those of the Chinese. But as late as the early 20th century, there was no unanimity on the relative value of boring vs. pitting for prospecting and exploration at the Malaysian tin deposits. By the time of World War I, however, a general concensus had emerged in support of pitting (*Ibid.*, p. 59). The regular use of the practice in Malaysia raises the question of whether borehole drilling was not perhaps used somewhat more frequently than presently available evidence suggests. In this connection, we have an interesting statement by the often well-informed William F. Collins: 'Prospecting by means of boring or drilling is said to have been introduced into America from China, where the practice probably originated.' Collins (1922), p. 15. Unfortunately, Collins gives no source or any kind of evidence for this statement. The subject awaits further clarification. What is clear is that by 1828, 'reasonably detailed reports were available to Europeans, and led to a series of imitations and tests of [percussion deep drilling using flexible belt-cables rather than rigid rods].' For a full and fascinating discussion, see Vogel (1991c), pp. 84–90. (The citation comes from p. 84.)

Table 12. *Mineral associations in the* Kuan Tzu

Cinnabar/gold	Cinnabar above, gold (*huang-chin* 黃金) or gold ore (*chu-chin* 銈金) below.
Magnetite/copper	Magnetitite above, copper (*thung-chin* 銅金) below.
Ling shih 陵石 /lead, tin, red copper	*Ling-shih*[a] above, lead and/or tin and/or red copper below.
Hematite/iron	Hematite (*che* 赭) above, iron below.
Lead/silver	Lead above, silver or silver ore (*chu-yin* 銈銀) below.

[a] Amano (*1953*, p. 236) identifies *ling-shih* as calcite (*fang chieh shih* 方解石). But cf. fn. 75.
Based on *KT*, ch. 23, pp. 1b–2a.

(α) *Mineral/mineral and mineral/rock associations*

The tendency of certain minerals, because of patterns of geological depositions, to be found together or close to each other was an especially valuable aid to traditional prospectors.[73] Though these associations were far from infallible, they could be learned easily from experience and contributed at the same time to a more systematised mining lore with potential for further development. Chinese miners from very early on seem to have paid particular attention to mineral associations, not only recognising them but seemingly even taking them for granted.[74] The *KT* contains two well-known (and very similar) passages, each giving several mineralogically reasonable examples of surface or shallow deposits (referred to simply as 'above' *shang* 上) that can be taken to indicate deposits of metals at depth (cf. Table 12).[75] The same attention to mineral associations pervades the *SHC*; associations such as gold and jade, jade and copper, silver and gold, gold (copper?) and iron, cinnabar, iron pyrites and alum are frequently noted.[76] By contrast, less evidence appears in the surviving sources on the recognition of the other great class of associations so essential to modern prospecting, the associations between rocks and minerals.[77]

[73] Information on such associations is presented in all books on mining that discuss prospecting, handbooks for prospectors and mineral collectors, etc. A very handy table of common rock-mineral associations is presented in Sinkankas (1970), pp. 179–80.

[74] Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 94.

[75] *KT*, ch. 23, 1b and 2a; Vol. 3, p. 674; Yang Wen-heng (*1978*), pp. 303–4 (trans. in Yang Wen-heng (1983), p. 262). Vol. 3 above presents a translation of the first of the two passages, while Yang Wen-heng translates the second. See also Huang Yü-heng & Ao Ta-chheng (*1989*), pp. 17–18 which suggest that the term *ling shih* 陵石 refers to the 'iron hat' (gossan) as well as a zone of brecciated rock.

[76] *SHC*, passim; Cheng Hsiao-chieh *et al.* (1985), pp. 1–146, passim; Yang Wen-heng (*1978*), p. 301; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 266; Vol. 3, pp. 674–5.

[77] In the West, too, the importance of these associations was not fully appreciated until the 19th century when miners came to understand that 'mineral deposits didn't just "happen" and that actually there were important connections between *kinds of rocks* and *kinds of minerals*.' (Sinkankas (1970), p. 79, italics in original.) Put this way, however, Sinkankas' point is perhaps somewhat misleading. It fails to distinguish clearly between the rock/mineral associations that prospectors and miners were well aware of through their practical experience and the understanding of why those associations occurred, on which they were completely in the dark; Rastall (1923), p. 87. Forbes is undoubtedly correct in suggesting that prospectors from a very early period were aware of the connection between igneous rocks and ore deposits and also knew that the ores they sought were likely to appear in acidic rather than in basic rock; Forbes (1963), p. 110.

Perhaps this is more a reflection of the interests of the authors of our sources than of the practice of prospectors and miners in the field. Rocks were of little medical or alchemical use. They were also generally less striking in appearance than many minerals. Hence, they would tend to be neglected by the authors of the pharmacological natural histories or of the many surviving alchemical works that provide so much of our information about traditional Chinese mineralogical knowledge. On the other hand, particularly striking rock/mineral associations did draw the attention of miners in the field, and were sometimes recorded by the bookmen. As mentioned above, cinnabar was associated as early as the Sung with a white rock (*pai shih* 白石), probably quartz, on which it was said to grow; thus the rock was sometimes called the 'bed' (*chu sha chhuang* 朱砂床) or the mother of the cinnabar.[78] The quartz/gold association was very dependable at least in certain parts of China, and was surely used by miners all the more since quartz is so recognisable.[79] The association between coal and China clays also seems to have been recognised at least as early as the Sung, and was frequently written about in later centuries.[80] Nevertheless, we can assume that less striking associations of rocks and minerals were often missed by miners in China as elsewhere.[81]

There was, to be sure, rarely any attempt to explain why any of those associations *should* exist.[82] Indeed, the very frequency with which we read of certain associations such as gold and jade for which there is no mineralogical basis suggests that these somehow quite early on became stereotypic ideas that then ceased to be tested against actual observation.

Mineral associations were often especially useful for more effective prospecting in a limited area where certain associations tended to prevail. For example, miners in Hunan learned that fluorite was a relatively reliable indicator of good tin deposits nearby, an association that was not especially important in other places where arsenopyrite was the best indicator of the presence of tin.[83] In southwest China, copper, silver and zinc were regularly associated.[84] In Kwangsi, there was a very strong association between limonite (formed from the weathering of the iron carbonate, siderite) and gold.[85] There were also useful negative associations.

[78] Cf. Section (*h*)(6) below; Vol. 3, p. 648; Vol. 5, pt. 4; de Mély (1896), p. 90; *TKKW*, ch. 16, p. 287; Sun & Sun (1966), p. 280. The quartz/cinnabar association is common in China; Tegengren (1920), p. 3.

[79] Wong Wen-hao (1920), p. 53. Diodorus Siculus in the −1st century described quartz as 'usually white and in brilliancy surpasses everything else which shines brightly by its nature . . .'. Cf. Healy (1978), pp. 84–5.

[80] Lü Tai-ming (*1986*), p. 194. The coal/alum and coal/pyrite associations were also well known; *Ibid.*

[81] Sinkankas (1970), p. 79.

[82] Explanations that are stated or implied, such as the presence of gold on the *yang* 陽 side of mountains and iron on the *yin* 陰 side, were not likely to help miners very much. Cf. Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 266. The same would be true of the many 'birth associations' where one mineral or material was believed to give birth to or produce another, as with the idea that potash feldspar (*yang chhi shih* 陽起石) gave birth to mica; Schafer (1955a), p. 266. While this may seem at first sight to resemble the modern concept of paragenesis, whereby certain minerals over time derive from earlier minerals (cf. Whitten & Brooks (1972), p. 337), these 'birth associations' in China were almost entirely imaginary, without geological or mineralogical foundation.

[83] Weng Wen-hao (*1919*), pp. 191–5. [84] Moore-Bennet (1915), p. 218.

[85] Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 266–7.

For example, miners in Hunan found that the presence of galena, the lead sulphide mineral, was usually an indicator of at best poor tin deposits.[86]

We have seen that the thinking of those who wrote about mining was often coloured by agricultural ideas. Thus, even mineral associations are often spoken of in terms of *miao* 苗 'outcrops' or, literally, 'sprouts' or 'shoots'. Tuku Thao, the +10th century author of the *Tan Fang Chien Yuan* (The Mirror of Alchemical Processes (and Reagents); a Source-book) is cited in *PTKM*: '*Yin phing chhien* 陰平鉛 (perhaps cerussite)[87] is produced in Chien-chou 劍州 (present-day Chien-ko hsien 劍閣縣 in Szechwan) and is a "sprout" (*miao*) of copper and iron.'[88] In the same way, the *PTKM* also quotes the *Pao Tsang Lun* 寶藏論 (Discourse on the Precious Treasury), a pre-Sung work of uncertain date, as claiming that a certain lead ore (*fu pan chhien* 負版鉛) is a 'sprout' of iron.[89] This is another case where the thinking of the bookmen and that of the miners, most of whom also came from a farming background, may well have overlapped. Still, such analogical concepts often leave us less than clear about just what the author had in mind. Sometimes, nothing more than a very general meaning such as 'indication' or 'indicator' seems to be implied by *miao*.[90] In any case, there was nothing in the miners' experience that would necessarily contradict such parallels between agriculture and mining. On the other hand, we have Ko Hung writing in the early +4th century: 'The Manuals of the Immortals say that the essence of cinnabar produces gold . . . That is why gold is generally found in the mountains below cinnabar deposits.'[91] Here, miners would know that this was less than a highly reliable association.[92]

(β) *Plant associations*

The Chinese use of geobotanical prospecting has been discussed at some length above.[93] It is a practice with a very long history in China. At Thung-lü shan 銅綠山 early prospectors must have been drawn to its rich copper deposits not only by the specks of verdigris that appeared in its soil after a rainstorm but also by the plant elshotzia (*thung tshao hua* 銅草花) which, in copper-bearing soil, produces beautiful blue flowers.[94] In southern Anhwei, there is a consistent association between copper and a similar flower, the 'copper rust flower' (*thung hsiu hua* 銅銹花) which, in the autumn, has blue flowers shaped like a toothbrush, leading to its local name as the 'toothbrush flower'.[95]

[86] Weng Wen-hao (*1919*), p. 193. By contrast, and a further example of local variations, we have seen above (Section (*e*)(1)(ii)) that the great tin deposits of Ko-chiu were discovered as a result of the working out of the galena deposits that had originally drawn miners to the area.

[87] Hsia Hsiang-jung *et al.* (*1980*), p. 279. [88] *PTKM*, ch. 8, p. 12; Hsia Hsiang-jung *et al.* (*1980*), p. 277.

[89] *PTKM*, ch. 8, p. 12; Vol. 5, pt. 2, pp. 213–14. [90] Vol. 3, pp. 649, 675.

[91] Vol. 5, pt. 2, p. 67. [92] Cf. Vol. 5, pt. 2, p. 277.

[93] Vol. 3, pp. 675ff. For brief but more recent discussions, cf. Yang Wen-heng (*1978*), pp. 304–5 (trans. in Yang Wen-heng (1983), pp. 262–3) and Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 266 (on botanical indicators of gold); and Ho Ping-yü (1981), (*1982*) and (*1982a*).

[94] Anon. (*1971*), p. 98 (with illustration); Anon. (1980), n.p.

[95] Yang Li-hsin (*1988*), p. 187. Other Chinese plant indicators of mineral deposits are the Asiatic plantain (*chhe chhien tshao* 車前草) for zinc ores, the meadow pine (*wen ching tshao* 問荊草) for gold ores, and the Chinese milk vetch (*tzu yun ying* 紫云英) for uranium; Anon. (*1971*), pp. 99–100 (with four line drawings of these plants).

Of course, one of the best signs of mineralisation was not any particular kind of plant but rather the absence of greenery. Mineral outcrops with pyrite (iron sulphide) as a significant component will be completely devoid of vegetation. Since pyrite is the most abundant primary vein material, barren areas in otherwise wooded regions provide a most important clue for prospectors.[96] But here too, even relatively well-informed observers were sometimes prone to over-generalise. For example, Sung Ying-hsing 宋應星 wrote in his *TKKW* that 'In the south, coal is found in bare mountains that lack vegetation and trees' and 'coal does not appear in areas where vegetation and trees abound'.[97] This is a case where geobotanical factors are of limited use in prospecting; surface vegetation or its lack are far from a reliable clue to the presence or absence of coal underground.[98] In part, Sung may have been misled by the fact that it is easier to discover outcrops in denuded areas than in those places where vegetation hides them from sight. Even more likely, however, Sung was probably thinking of the coal deposits in the Kao-an 高安 and Shang-kao 上高 area of Kiangsi, right next to his birthplace, Feng-hsin 奉新. There the ubiquitous limestone does inhibit vegetation.[99] There are, however, many areas especially in south China but also in the north where coal is present along with luxuriant vegetation. Indeed, the Shansi provincial gazetteer even notes that: 'Coal is relatively abundant in the prefectures of Shansi. Where it [appears to be] lacking, it is because collecting firewood from the mountains is easier than digging coal.'[100]

(5) Rock and Mineral Identification

Well before the appearance of *Homo sapiens*, the ancestors of today's Chinese were already honing their ability to distinguish nature's inorganic products when they chose certain stones to serve as tools and implements, while rejecting others.[101] As an increasing variety of rocks and minerals, some of them not easy to recognise in their natural forms, came to be used for different purposes, the ability to identify these materials increased in importance and skills of this type improved accordingly.

Even in those cases where identification of a mineral is relatively easy, it is rare that it can be identified by a single physical or chemical property. The Chinese early came to understand this and typically identified minerals by using a package of characteristics, such as various aspects of their appearance (colour, shape, lustre),

[96] Healy (1978), pp. 71 and 24. Such clues were even clearer when accompanied by waters that had been coloured by mineral deposits; Anon. (*1971*), pp. 99–100.

[97] *TKKW* 11, pp. 202–3; Sun & Sun (1966), pp. 205–6.

[98] Lü Tai-ming (*1986*), p. 192. [99] Hsia Hsiang-jung *et al.* (*1980*), p. 397.

[100] *Shan Hsi Thung Chih*, cited in Hsia Hsiang-jung *et al.* (*1980*), p. 397.

[101] Remains as early as those of Peking Man at Chou-khou tien 周口店 reveal a clear evolution toward the increased use of better quality rocks for tools; Hsia Hsiang-jung *et al.* (*1980*), p. 8. In the top layers of the Chou-khou tien excavations, green standstone virtually disappears as a tool material while there is a great proliferation of flint implements. In later times, the toolmakers of today's north China probably experimented with as great a variety of stones as any other early people, from some 13 kinds used in the Paleolithic period (Yang Wen-heng (*1978*), p. 300) to almost 50 different kinds by the end of the Neolithic period (Cheng Te-khun (1959), (1960) and (1966)). See also Hu Sung-mei (*1992*).

their hardness, how they broke, and the like. Moreover, with the Chinese bent for analogical thinking, they frequently tried to describe minerals in terms of something else that they resembled. And since they did not draw modern chemistry's sharp line between organic and inorganic materials, they often turned to living things to describe what a given mineral was 'like'. As an agricultural people, they quite naturally borrowed from common plants an array of appearances that could be used to describe minerals, such as bran-like gold flakes (*fu-chin* 麩金). Animals could also serve for comparision. Perhaps one of the best examples is the reference to gold nuggets as 'dog's head gold' (*kou thou chin* 狗頭金).[102] Anyone who has observed a fair number of dog snouts and gold nuggets will hardly care to challenge the comparison, even though it rests in part on a very subtle sense of resemblance, difficult to put into words.

However accurate or subtle these identifications might be, they relied in all cases solely on properties that could be perceived with the unaided senses.[103] As was true for all peoples in premodern times, Chinese efforts to identify, describe and classify minerals were frustrated by lack of understanding of chemistry and crystallography.[104] The problem was less serious with those minerals that have a fixed chemical composition that gives them consistent, relatively easy-to-recognise physical characteristics. But there are many other minerals which consist of a series of related compounds where one metallic element may replace another wholly or in part. This will sometimes result in specimens that appear quite different but are chemically very similar. By contrast, minerals similar in appearance may often be quite different in chemical composition, though that would be very difficult to determine with the tests available to Chinese miners, alchemists, and pharmacologists before the 19th century.

In the discussion that follows, we shall try to isolate from among all the methods of identification described mainly in the alchemical and pharmacological works those methods that were of potential use to miners in the field and likely to be known by them. Unfortunately, as we have already noted above ((*c*)(2)), the things that interested miners regarding minerals were often quite different from what concerned alchemists, pharmacologists and doctors. For example, miners naturally had to focus on the main markets for their production. Thus certain minerals of some importance in the making of medicines and elixirs might have had much larger markets for other purposes. Mica is a good example. Thao Hung-ching, considering the medical possibilities of mica, was especially concerned to distinguish those micas that were edible, and at what season of the year.[105] Most of the mining of mica in China, however, was not for medicinal but rather for ornamental purposes, as a surface for paintings, for lantern windows, and for ordinary window panes.[106] Now there was no difficulty in identifying mica in general; its appearance in 'books' with unique perfect cleavage into very thin elastic plates made it unmistakable. Beyond

[102] Cf. above, Section (*e*)(1)(iv). [103] Wheeler & Maddin (1980), p. 99.
[104] Hoover & Hoover (1912), p. 594; Bandy & Bandy (1955), p. vi. [105] Vol. 3, p. 648.
[106] di Villa (1919), p. 89; Anon. (1898–1899), p. 743; Schafer (1955a), p. 277.

that, however, the main market for mica emphasised aesthetic and practical considerations: was it of good colour? was it clear or cloudy? could it be made into sheets large enough for practical use?[107]

Our discussion will be further hampered by the paucity of hard evidence relating to actual techniques used by miners in the field. On the other hand, if we allow that at least some of the 'knowledge' of the alchemists and pharmacologists was informed by the practical experience of men in the field, and further keep in mind those skills that miners everywhere inevitably acquire in the practice of their profession, we can construct a reasonable inventory of techniques that were probably used by at least some Chinese miners to help them identify what they found.

(i) *General appearance and shape*

In considering what surviving documents reveal about the many methods used in China for identifying minerals, we must remind ourselves that miners also acquired over long experience intuitive skills that seldom found reflection in the written records. Particularly when it comes to the ability to identify the minute specks that indicate the presence of a metal or its ore, nothing substitutes for long, one might say 'eyes-on' training and experience. This helps account for the great amounts of time people in hardrock mining communities spend looking at and discussing rocks (Fig. 28).[108]

General appearance was often at least a good clue for identifying a mineral, as in the case of the flat scales of some placer gold, the sometimes rusty-coloured honeycombed dinginess of gold-bearing quartz, the waxy, horn-like look of cerargyrite (silver chloride), the fibrous or thread-like structure of asbestos and some native silver, and the scaly character of mica.[109] Some examples above (Section (*f*)(4)) have shown how experienced miners could not only identify a specimen just by looking at it but could also, in some cases, judge its richness. On the other hand, as we also noted, such identifications could also be way off the mark. Again, experience was the key, as Mark Twain points out in describing miners in the American west: 'I will remark here, that although to the inexperienced stranger all the quartz of a particular "district" looks about alike, an old resident of the camp can take a glance at a mixed pile of rock, separate the fragments and tell you which mine each came from . . .'[110]

[107] Chinese deposits of mica do not seem to have produced anything like the sheets 3 m across that could be found in India. The largest sheets I have seen reference to were a mere 15 cm across; Torgasheff (1930), p. 401. This helps account for the relatively small importance of mica mining in China.

[108] Even with the advances of modern science and technology, such skills have by no means lost all of their importance. One need only think of the lab. specialist or doctor examining a tissue sample for indications of cancer. These skills, to some extent taken for granted by those who possess them, are seldom very well understood by people to whom they are foreign.

[109] We have earlier referred to the appearances that lay behind some of the terms used to designate the copper carbonates malachite and azurite; cf. Section (*e*)(1)(i)(α).

[110] Twain (1873), p. 277. Compare the miners at Yin-chheng, Shansi, a locale with nine or ten seams of coal, who said they could easily tell from what seam a hand-specimen had come; Shockley (1904), p. 851.

Fig. 28. A favourite pastime of hardrock miners: carefully examining and discussing rock samples for clues to ore deposits. It is a skill that words can capture only crudely; it can be mastered only by long practice. (The rock and magnifying glass are in the hands of Hu Chhu-Yen 胡楚雁, Professor of Geology at Kuei-lin Institute of Technology 桂林工学院, who was my guide during a very fruitful field trip in August–September, 1994 to gold mines south of Kuei-lin in Kwangsi.) Original photo, 1994.

Chinese mineralogical terminology is replete with colourful descriptions of minerals based on their general appearance. We have just mentioned above 'dog's head gold' (*kou thou chin* 狗頭金). There was also 'old man's beard' (*lao weng hsu* 老翁須) for a fibrous appearance, 'worm excrement' (*chhiu yin ni* 蚯蚓泥) for bits of native gold, and 'dragon sprouts' (*lung ya* 龍芽) for dendritic silver. Despite the impressionistic character of many of these terms, they could sometimes evolve into a rough-and-ready standardisation of usage. This happened in the case of grains of native placer gold. Today, Chinese refer to grains with a diameter of 0.25–2.00 millimetres, with approximately 2,200 grains weighing one ounce, as 'medium-sized grain gold' (*chung li chin* 中粒金); this size grain was commonly referred to in traditional writings, and probably among miners as well, as 'bran gold' (*fu-chin* 麩金). Somewhat larger grains, today called 'coarse-grained gold' (*tshu li chin* 粗粒金) were formerly known as 'melon seed gold' (*kua tzu chin* 瓜子金). Finer particles, now *hsi li chin* 細粒金, were regularly known as 'chaff gold' (*khang chin* 糠金).[111] In conditions where minerals are able to develop freely, they tend to grow in more or less regular geometric forms called crystals. If not in crystal form, minerals are massive or amorphous, that is, entirely irregular. The shape of a mineral is called its habit.[112] Even before the advent of modern inorganic chemistry, crystal structure, which directly reflects the organisation of the molecules of a mineral, was a very important tool for the identification if not the understanding of minerals. As has been noted elsewhere (Vol. 3, p. 648), Chinese works on minerals paid a great deal of attention to crystals. The +11th century *Pen Tshao Thu Ching* describes quartz crystals of six faces (*mien* 面), thus identifying their hexagonal system.[113] Early in the following century, Khou Tsung-shih 寇宗奭 in his *Pen Tshao Yen I* 本草衍義 (Dilations upon Parmaceutical Natural History) described *phu sa shih* 菩薩石, a form of quartz.[114] He remarked that it was six-sided, with its end coming to a point (*liu-leng erh jui-shou* 六棱而銳首), that is, a hexagonal pyramid.[115] The description in the *Pen Tshao Thu Ching* 本草圖經 (Illustrated Materia Medica) of calcite crystals as 'square and angular' (*fang-leng* 方棱)[116] seems to point to their rhombohedral system which has three axes of equal length ('square') but, in contrast with the hexagonal system, an angle other than 90° between them ('angular'). The description in the *Lei Kung Yao Tui* 雷公藥對 (Answers of the Venerable Master Lei (to Questions) Concerning Drugs) of cinnabar crystals with 14 sides may well refer to twinned rhombohedra, as suggested above.[117] A text from the middle of the +12th century mentions that the best quality Wu-chhang 烏長

[111] Lu Pen-shan & Wang Ken-yuan (*1987*), p. 75. Compare also Sung Ying-hsing's catalogue of distinctive terms used for the gold from different kinds of deposits; *TKKW*, ch. 14, p. 233; Sun & Sun (1966), p. 236.

[112] Probably the most widely used text on crystals is *Dana's Manual of Mineralogy*. I have used the 18th edition, revised by Cornelius S. Hurlbut, Jr. (Dana (1971)).

[113] Vol. 3, p. 648. For a very detailed discussion of Chinese writings on crystallography, see Lu Hsueh-shan (*1984*).

[114] But here probably not aventurine quartz as suggested by Rémusat and accepted by de Mély (Read & Pak (1928:1936), p. 26, No. 42) because aventurine is a cryptocrystalline quartz whose crystals would be so small that they could be seen only through a microscope; Sorrell & Sandström (1973), p. 208.

[115] Lu Hsueh-shan (*1984*), p. 3. [116] As cited in the *Thu Ching Yen I Pen Tshao*, ch. 1; see Vol. 3, p. 648.

[117] Vol. 3, p. 649.

(Ludhiana) saltpetre is shaped like little goose quills, perhaps a reference to prismatic crystal form.[118]

Although crystal form could be a great help in the identification of minerals, it was by no means infallible. The Chinese in traditional times had not worked out an objective method or system for describing crystal forms. All too often, they fell back on analogical descriptions such as prickle-shaped (*mang* 芒), tooth or horse-tooth shape (*ya* 牙, *ma-ya* 馬牙) that were none too clear.[119] Moreover, they may have sometimes given too much weight to crystal form while underplaying other properties, though miners with their working knowledge of the minerals may have been less prone to this error.[120]

(ii) *Colour and lustre*

Colour and lustre must have been the first characteristics of minerals to draw the attention of primitive man, in China as elsewhere.[121] The pleasing colour-and-lustre combination of stable, shiny metals like gold and silver have caused them to be prized down to the present.

Minerals are typically allochromatic, that is, they can appear in a range of colours because of the presence or absence of pigmenting materials. Even if colourless themselves, they can take on one or more colours from their impurities.[122] For identification, then, a particular lustre is likely to be a more reliable indicator of a given mineral than a certain colour.[123] Nevertheless, because of the far broader range of identifiable and nameable colours compared with lustres, there was a strong tendency for early identifications of minerals and their ores to be based in the first instance on colour.[124]

Moreover, certain exceptions to the allochromatic rule proved very important in the earliest stages of mining. In particular, malachite and azurite, with their characteristic green and blue respectively, are ideochromatic. Dependably recognisable, easy to mine and easy to smelt, these two copper carbonates were the two most important early copper ores.[125]

118 Vol. 5, pt. 4, p. 188. 119 Vol. 5, pt. 7, pp. 99–101.

120 Vol. 5, pt. 7, pp. 101–3. Confusion could arise in those cases where the crystal forms of different minerals were similar or, conversely, where the same mineral might display different crystal forms. Potassium nitrate, for example, is dimorphous and can form rhombic crystalline plates or needle-like rhombohedral (trigonal) crystals.

121 Wheeler & Maddin (1980), pp. 99–100.

122 Some minerals even change colour on exposure to light. For example, deep-red realgar gradually changes into yellow orpiment; Bauer (1974), p. 23.

123 There can also be variations in the lustre of a mineral; Sorrell & Sandström (1973), p. 56; Bauer (1974), p. 24.

124 Bromehead (1945), p. 113.

125 Other important ideochromatic minerals are sulphur (yellow), graphite (black), galena (silver to lead-grey), pyrite (pale brass yellow, tarnishing to brown) and chalcopyrite (the copper iron sulphide that is now the most important copper ore: pale brass yellow, tarnishing darker). Cinnabar, though it could on occasion appear as grey to black (or, with Chinese precision, as the colour of the unopened lotus; *PTKM*, ch. 9, p. 52), typically announced itself clearly because of its bright, scarlet colour. On the other hand, it could be and was mistaken for the silver arsenic sulphide proustite (ruby silver, light red silver) which could have both the same colour and the same streak (cf. below); Hsia Hsiang-jung *et al.* (*1980*), p. 311.

Throughout the traditional period, the Chinese continued to place very great emphasis on colour in the identification of minerals.[126] As the 'Ta Yeh Fu' 大冶賦 of Hung Tzu-khuei 洪咨夔 notes: 'Experienced miners can also distinguish copper ores by viewing them. In water, the ores give off different appearances. Those with intermixed hues of red and white are the best. Purplish ores with reddish markings are also quite good.'[127] To some extent, the association of the five metals with the five colours in Chinese cosmological correspondence theory (gold/yellow-brown; silver/white; copper/red-scarlet; iron/black; tin-lead/caerulean) may have reinforced the emphasis on colour for identifying minerals among scholars, alchemists and pharmacologists,[128] but it is hardly likely to have had much influence on prospectors and miners. As for the problem of allochromaticism, it was ordinarily dealt with, though with limited effectiveness, by associating various colours of what was recognised to be the same mineral with deposits in different locations.[129]

Colour was also relied on to distinguish variations of a given mineral. Mica offers a good example. In the +5th century, Thao Hung-ching 陶弘景 cited an earlier work, the *Hsien Ching* 仙經 (Manuals of the Immortals)[130] which distinguished eight different kinds of mica, primarily by their colours.[131] Unfortunately, the range of colours within a given type of mica makes this a tenuous categorisation at best and today we are able to make more or less tentative identifications of only four of the described micas.

Jade and certain precious or semi-precious stones were sometimes identified by the play or change of colours when they were viewed from different sides. Thus, a certain kind of agate (*lai thai ma nao* 來胎瑪瑙) was white when viewed head-on but became the colour of coagulated blood when seen from the side.[132]

To use colour for identifying a mineral, it is ordinarily important to check the colour on a freshly broken surface. Chinese miners must have been aware of this from very early times, but the first explicit textual reference does not appear before the late +16th century *PTKM*: '[The cinnabar of Hsin-chou 信州] is similar to that produced at I-chou 宜州 but it partakes of the *chhi* 氣 of arsenic and, *when broken*, is frequently the colour of raw arsenic.'[133]

Lustre, the sheen or gloss of a mineral's surface, varies depending on the amount and kind of reflection and refraction of light and also on the nature of the surface of the mineral. Apart from metallic lustres, there are many kinds of non-metallic lustres, including (with some examples): earthy (hematite); vitreous or glassy (quartz); pearly (opal); resinous (sphalerite); greasy (talc); silky (serpentine) and adamantine or diamondlike (diamond).

126 This was true also for gemstones. Sung Ying-hsing, in the +17th century, classified the major gemstones familiar to Chinese into two groups: the red/yellow gems and the blue/green gems; *TKKW* 18, p. 306; Sun & Sun (1966), pp. 299–300.

127 *Phing Chai Wen Chi*, ch. 1, p. 5a.

128 Cf. Vol. 5, pt. 4, p. 225.

129 Wang Chia-yin (*1957*), p. 61 and see, for example, the various cinnabars discussed in *PTKM*, ch. 9, pp. 51–2.

130 Supposedly available to Liu An 劉安, the prince of Huai-nan 淮南 in the –2nd century.

131 *Thu Ching Yen I Pen Tshao*, ch. 1, p. 8a; see Vol. 3, p. 648; Lu Hsueh-shan (*1984*), p. 4.

132 Lu Hsueh-shan (*1984*), p. 18.

133 *PTKM*, ch. 9, p. 52, italics added.

Most of the discussion of lustre in Chinese writings on minerals seems to have focused on jade, jade-like minerals and jade-bearing rocks. Thao Hung-ching, for example, described these minerals as having the glossiness of pork fat.[134] A test one could perform to see if a rock contained jade was to hold it up to a lamp; if a gleam like that of the rising sun appeared inside the rock (because of its translucent fluorescence), that indicated that there was jade in the rock.[135]

Through experience, Chinese miners must have recognised that the richness of silver–lead ores could be inversely related to the brightness of their lustre, though we cannot know whether they accepted Sung Ying-hsing's explanation for this phenomenon: 'The more the [silver] ore glitters, the more its essence (*ching-hua* 精華) dissipates and the less silver will be obtained from it.'[136] This seems to refer to cases where a lead-grey silver ore such as argentite is found in galena. These ores are typically darkened on the surface so that a brighter lustre results from a greater proportion of galena and correspondingly less silver ore.[137] On the other hand, in Yunnan early in this century, 'ores of a fine granular appearance, compact and massive, and *exhibiting glittering facets* on the broken surface of a fractured specimen [were] considered to be the richest in silver.'[138]

An anonymous author has suggested that lustre was used in assaying the quality of tin ore at Ko-chiu 箇舊 in Yunnan: 'To determine the metal content of the ore, water is poured into a bowl containing a handful of ore. The bowl is shaken with jerks, thus separating the earth, and causing the metal to glitter. From the brilliancy of the metal, one is able to form an opinion as to the quality of the ore. This practice explains why bowls are found in such numbers on the Ko-chiu ore market.'[139] My observation of this process at Ko-chiu in the summer of 1990 did not confirm this interpretation, however. Though one can make out the tin along the upper edge of the washed material, as can just barely be seen in Fig. 117(*d*) below, it appeared black in this demonstration, without any particular lustre and certainly displayed no 'brilliancy'.

One of the most useful colour tests for identifying many minerals is the streak test. Streak refers to the colour of a mineral in powdered form, which is often quite different from its normal colour. A powder sample is most easily obtained by rubbing the mineral against another surface, nowadays normally a plate of unglazed porcelain.[140] Many minerals leave a white scratch, which is of no help. But all hematite, whatever its surface colour, leaves a blood red to brownish-red streak. The Chinese in traditional times were probably aware of this identifying characteristic: the *PTKM* noted that, by breaking a piece of hematite (*tai che shih* 代赭石), one

[134] *PTKM*, ch. 8, p. 36; Wang Chia-yin (*1957*), p. 59.

[135] PTKM, ch. 8, p. 36; de Mély (1896), p. 52; Wang Chia-yin (*1957*), p. 59.

[136] *TKKW* 14, p. 236. Cf. also Sun & Sun (1966), p. 241. [137] Hsia Hsiang-jung *et al.* (*1980*), p. 290.

[138] Brown (1923), p. 134. Emphasis added. [139] Anon. (1926), p. 155.

[140] Since porcelain has a hardness of 5.5–6.5 on the Mohs hardness scale (see note 156 below), the hardness of the mineral must be below that level or the scratching will produce only white porcelain powder. This limitation can be circumvented by first grinding or crushing the mineral to a powder and then rubbing the powder on the streak plate.

could obtain red fragments with which one could punctuate or annotate books or other writings (*tien shu* 點書).[141] Experimenting with various hematites could easily have led to the discovery that even hematite that was not red left a red streak. Li Shih-chen explained how to apply the streak test to orpiment: the highest quality material would leave an attractive colour when rubbed on the fingernail.[142] Apart from hematite and orpiment, we can also note the greenish-black streak of yellow pyrite, the brown streak of black tungsten and the almost colourless streak of black cassiterite.[143] Generally, it is minerals of a metallic lustre that show the greatest difference between their visible colour and their streak.

The Chinese may also have been the first to use what might be called the hot streak test, also to test the purity of orpiment. The *PTKM* explains that if orpiment drawn across a hot iron leaves a reddish-yellow steak, it is of good quality.[144] The *PTKM* also notes that this test was used for distinguishing alum.[145]

A variation of the streak test is the use of the 'touchstone' for assaying alloys of gold (and silver). As noted above, the touchstone was an important forerunner of the colorimetric and nephelometric methods so important in modern chemistry and biochemistry.[146] In contrast to streak plates which are light in colour, touchstones are typically a lustrous and black or blue-black cryptocrystalline variety of quartz (chert) or basalt (basanite) (Fig. 29).[147] The material to be tested would be rubbed across the touchstone and its streak compared with the streaks made by one or more bars or needles of standard compositions so as to find the closest match. The differences in colour and reflectivity became more pronounced by the fine dividing of the metal on the abrasive surface of the dark stone. The touchstone was used by the Chinese possibly as early as the Later Han. Chang Shu 張澍 of the Chhing, in his *Shu Tien* 蜀典, cites a statement from the commentary by Kuo Phu 郭璞 (+276 to +324) to the *SHC* in which he says: 'Electrum (*huang chin* 黃金) is mined in Szechwan. [In outward appearance (?)] it is indistinguishable from gold (*yü chin wu i* 與金無異) but when [rubbed] on a [touch]stone, its colour (i.e. streak) is white (*tan shang shih tse se pai* 但上石則色白).'[148] It seems quite clear that the touchstone was in wide use by the Sung. Schafer notes that Tu Wan of the Sung describes the touchstone in two places, without having a special name for it.[149] Another Sung author, Fang Shao 方勺 (+1066 to after +1141), in his *Po-chai Pien* 泊宅編 (A Compilation from Po-chai Village),[150] stressed streak colour as a more dependable means of determining the purity of gold than its outer appearance, where a certain

141 *PTKM*, ch. 10, p. 6; de Mély (1896), p. 109.

142 *PTKM*, ch. 9, p. 70; de Mély (1896), pp. xxxviii and 13; Schafer (1955), p. 76.

143 Cf. Bauer (1974), p. 23.

144 *PTKM*, ch. 9, p. 70; Wang Chia-yin (*1957*), p. 60; de Mély (1896), p. 81.

145 Lu Hsueh-shan (*1984*), p. 17.

146 Vol. 3, pp. 672–3. See there for use of the touchstone in the West at least as early as the −6th century.

147 Schafer (1961), p. 76; Lu Pen-shan & Wang Ken-yuan (*1987*), pp. 76–7.

148 This text is cited in Lu Pen-shan & Wang Ken-yuan (*1987*), p. 76; I have followed their interpretation. See also Chao Khuang-hua (*1990*), p. 249. Unfortunately, this passage tells us nothing of the kind of stone used or its colour. Nevertheless, it would not have taken very much experience, once the streak test had been discovered, to realise that darker stones were more effective in some tests than lighter stones, and that certain darker stones like basanite were better for this purpose than others. For the kinds of stones used as touchstones in China, see Lu Pen-shan & Wang Ken-yuan (*1987*), p. 78. See also Vol. 3, p. 673.

149 Schafer (1961), p. 76. Contrast Vol. 5, pt. 2, p. 48.

150 On this work, see Balazs & Hervouet (1978), p. 290.

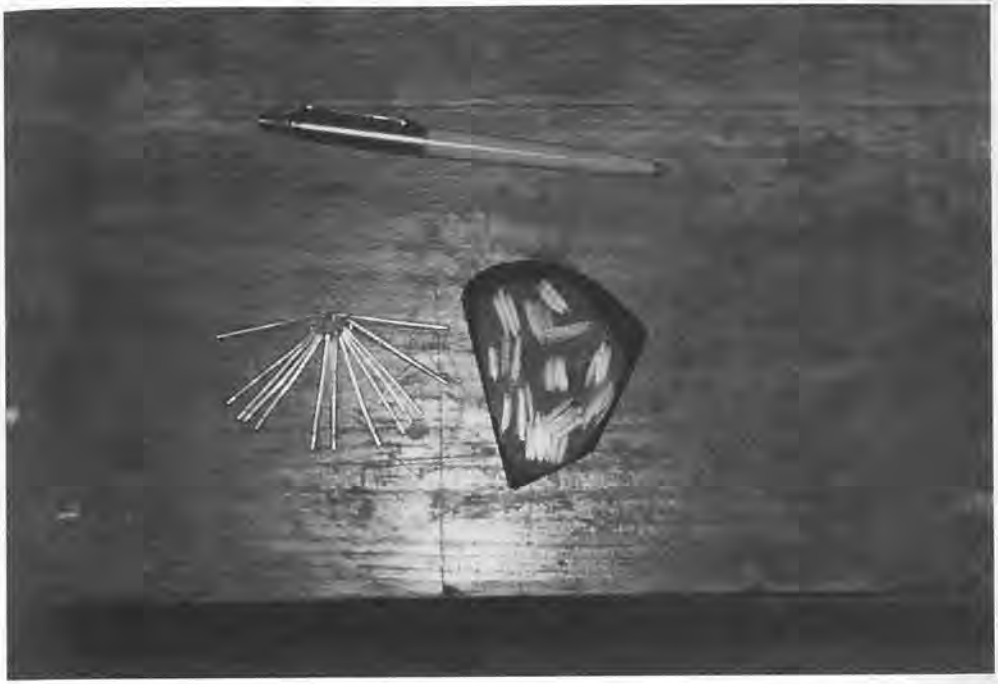


Fig. 29. A touchstone currently used at the gold mines of Thao-hua 桃花, Kwangsi. The marks on the touchstone were made by the various needles on the left, each of which was labelled with the percentage of gold contained in the sample. A skilled miner or metallurgist, however, could quite accurately estimate the gold percentage without looking at the labels. Original photo, 1994.

amount of silver may bring no noticeable change in the colour.[151] By the +14th century, the term 'gold testing stone' (*shih chin shih* 試金石) had come into use.[152] Miners surely knew of such tests, though it is not likely that they often made use of them in their daily activities. Especially when it came to assaying the purity of gold, the task was in all likelihood put into the hands of assay experts.

(iii) *Opacity*

Whether a mineral was opaque, translucent or transparent was sometimes useful not for identification but for helping to distinguish the quality of different specimens. Both lustre and opacity were important for ranking different kinds of cinnabar according to their suitability for use in medicine or alchemy. Chhen Shao-wei, in his extensive and detailed discussion of cinnabar in perhaps the early +8th century, makes the following distinctions: 'Of (the purple numinous cinnabar) produced in Chiao-chou 交州 and Kuei-chou 桂州, only that which occurs in throne formations

[151] *Po-chai Pien*, ch. 6; cited in Lu Pen-shan & Wang Ken-yuan (*1987*), p. 76.
[152] Schafer (1961), p. 76; Lu Pen-shan & Wang Ken-yuan (*1987*), p. 77.

or which is found inside rocks when they are broken open, and is shaped like lotus buds and lustrous, is also included in the highest grade. That which is granular in form and translucent (*thung ming* 通明), three or four pieces weighing a pound, is of the middle grade. That which is laminar in form and transparent (*ming chhe* 明徹) is of the lower grade.'[153] This passage reminds us that Chinese miners must have been influenced at least to some extent by the identification criteria of pharmacologists, doctors and alchemists even when they had no knowledge of or concern for the theories that lay behind these criteria. After all, these people represented a not insignificant market for certain minerals like cinnabar. Successful miners would know what their customers wanted and would pay for.

(iv) *Properties of cohesion: hardness, cleavage, fracture and tenacity*

As a result of the structure of their crystals, minerals can be distinguished according to their cohesion properties, that is, the way they resist or submit to breaking, crushing, bending or tearing.[154]

Tests for hardness offered a rather rough but easy technique for helping to identify minerals. Perhaps one of the earliest hardness tests was invented by a prospector who, knowing gold should be much softer than 'fool's gold' or pyrite, took a suspected gold nugget in his mouth and bit it. Though our first written evidence for a Chinese use of this easy test dates from the Thang,[155] it was undoubtedly known much earlier.

Today, the most common in-the-field test for hardness consists of determining what minerals or objects (e.g., a copper coin) of known hardness will scratch or be scratched by the mineral being examined.[156] The accuracy of hardness tests is limited because weathered minerals may have been softened on their surface, because some minerals are harder in one direction than in others, because intergrown soft aggregates in harder minerals can sometimes lead to widely varying and difficult to interpret hardness readings, and because the angles and edges of a crystal are sometimes harder than its internal cleavage planes. Then, in the case of earthy, needle-shaped and fibrous minerals, as well as efflorescences and fine grained aggregates, simple hardness tests are useless.[157] Nevertheless, hardness tests have long been popular among miners and prospectors because they do not require any special equipment and are easy to perform. We seem to lack any evidence, however, of just what hardness tests were used by Chinese miners.

153 Vol. 5, pt. 4, p. 238.

154 Bauer (1974), p. 19; Pearl (1973), p. 220; Healy (1978), p. 28. Most minerals are brittle, but a few cohere in special ways: for example, chlorite is flexible, gold is malleable, mica is elastic, metals tend to be ductile.

155 Schafer, (1963), p. 251.

156 Nowadays, hardness is most frequently described in terms of the Mohs scale which consists of ten minerals of increasing ardness: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) microline; (7) quartz; (8) topaz; (9) corundum; and (10) diamond. A mineral that can be scratched by microline but not by apatite is said to have a hardness between 5 and 6.

157 Bauer (1974), pp. 20–1.

We are a little better able to assess the extent to which Chinese miners identified minerals by considering fracture (the breaking of a mineral in irregular fashion, i.e., not along even planes)[158] and cleavage (the regular breaking of certain minerals along surfaces that are related to their internal crystal structure).[159]

One of the most distinctive forms of fracture is conchoidal or 'shell-like'.[160] Conchoidal fracture was well known from very early times to those Chinese who were fortunate enough to discover that flint, chert, chalcedony and obsidian (rhyolite), all stones with conchoidal fracture, are capable of being nicely flaked or chipped into tool shapes.[161] This intimate connection between the kind of fracture that occurred and the usefulness of the stone for fabrication into a tool assured that fracture would be a primary means of identifying rocks (as opposed to minerals) at least until stone tools came generally to be replaced by iron tools in the second half of the –1st millennium. Conchoidal fracture continued to be familiar to miners in later periods because of the importance of cinnabar mining in China. Su Sung 蘇頌 describes the conchoidal fracture of certain native cinnabars in his *Pen Tshao Thu Ching* 本草圖經 (Illustrated Materia Medica): 'Upon breaking the lumps of the mineral, it is seen to form precipitous slopes (with surfaces) like walls, as smooth inside as plates of mica....'[162]

A prominent form of cleavage is the perfect one-directional cleavage of mica and orpiment, usually referred to as micaceous or lamellar cleavage. Although our first explicit reference to it dates only from the +5th century,[163] the use of both of these minerals from very early times undoubtedly led to early recognition of this characteristic by Chinese miners. Particularly in the case of orpiment, it presumably helped miners distinguish it from sulphur, the other yellow mineral found in similar environments (low-temperature hydrothermal veins) but which lacks the very good one-directional cleavage of orpiment as well as its flexible cleavage flakes.[164]

The tenacity characteristics of minerals (malleability, brittleness, sectility, ductility, flexibility, elasticity) could hardly fail to be noticed by miners in the course of their excavations, but there seems to be little or no reference in the surviving sources to their use in the mines to identify minerals.

[158] Some forms of fracture are: even, uneven, conchoidal, hackly (jagged), fibrous or splintery, blocky and prismatic.

[159] Four characteristics of cleavage can be observed: (1) the number and direction of the cleavage plane(s) (e.g., the tendency of galena or halite to break in three directions at right angles to each other and thus form cubes vs. the basal, one-directional cleavage of mica and gypsum); (2) ease of cleavage, from perfect (e.g. mica) through good and fair to poor or obscure (that is, lacking in identifiable cleavage, such as beryl, apatite); (3) the regularity of the break; (4) the lustre of the break surface.

[160] It 'takes the form of a curved, concentrically ribbed surface, not unlike the shells of some lamellibranchs.' Whitten & Brooks (1972), p. 97.

[161] Cheng Te-khun (1959), pp. 20, 35, 42, 45, 48, 55, 62, 105, 120, 137, and 141. The absence thus far in the archaeological record of any evidence for the mining of these stones suggests, though it hardly establishes, that China's deposits were rather limited when compared with many other stone-tool cultures. Cf. Section (*g*) below.

[162] Vol. 3. p. 649.

[163] *PTKM*, ch. 9, p. 70, citing the shadowy physician, pharmacologist and alchemist, Lei Hsiao 雷斅; Schafer (1955), pp. 75–6. The term used here and elsewhere for 'cleavage' was *che* (折 or 析); Lu Hsueh-shan (*1984*), p. 15.

[164] Sorrell & Sandström (1973), p. 84.

(v) *Density*

Minerals vary in their density, or weight per unit volume. Today, the common measure of the density of minerals is specific gravity, or the weight of a given amount of the mineral in air compared with its weight in water. The calculation of specific gravity is complicated by the influences of temperature, porosity, crystal structure, impurities in the sample, etc. The experienced prospector or miner, however, learns how to distinguish densities at least approximately by simply hefting a specimen in the hand. Indeed, the varying densities of different materials were necessarily understood intuitively by the earliest miners long before they could have put the concept into words. Once miners working placers began to replace grubbing with panning (cf. below, Section (*g*)(1)(i)), they were relying on the difference in density between the minerals they sought and associated waste materials.

The *Sun Tzu Suan Ching* 孫子算經 (Master Sun's Mathematical Manual), which dates from between +280 and +473, gives a list of the densities of gold, silver, copper, lead, iron, jade and 'stone', expressed in the weight of a cubic *tshun* 寸.[165] Li Ti has converted the figures given for gold, silver, copper, lead and iron into specific gravities and compared them with the currently accepted figures. Although Sun's density figures are not as accurate as those of the Arabs some eight centuries later, they were close enough to serve as a standard in China for some 1,500 years.[166] Interestingly, the largest error in both the *Sun Tzu Suan Ching* and in the *TKKW* more than a thousand years later is in the making of gold only slightly more dense than silver.[167]

(vi) *Touch, taste, smell and sonority*

In those cases where touch provided a means for identifying a mineral or the quality of an ore, it could be an especially useful test in the darkened conditions of an underground mine. In the early days of California mining, one Cornish miner acquired the nickname of 'Old Velvet Thumb' because he was supposedly able to detect the

[165] Vol. 3, p. 33.

[166] Li Ti (*1984*). Li discusses some practical uses of the concept of density (dating back to a float test for checking wheels in the Warring States period) but surprisingly has nothing to say about the most common practical use of density variations: the process of washing (or panning) to select out heavy minerals from their lighter gangue. For other examples of early Chinese awareness of varying densities, see Vol. 4, pt. 1, p. 39.

[167] In the *Sun Tzu Suan Ching*, however, the ratio between the densities of copper and gold is relatively accurate while the silver/copper ratio assigns too great a density to silver. In the *TKKW*, on the other hand, the copper/gold ratio is far off because the silver/copper ratio is relatively accurate; Li Ti (*1984*), p. 123; *TKKW* 14, p. 234 (Sun & Sun (1966), p. 236). De Mély (1896, p. xxxi) pointed out what he considered to be a remarkable lapse in the generally good powers of observation of the Chinese: they apparently did not note that, of all the metals, only gold would sink in mercury. In fact, the *PTKM* (ch. 9, p. 57) explicitly says just the opposite, that *all* the metals would float on mercury. Yabu'uchi (*1969*, p. 262, n. 2) suggests that the *TKKW* discrepancies were largely due to impurities in the samples but one wonders why the ratio of the densities of copper and silver is quite accurate while that of silver and gold, in obtaining pure samples of which the Chinese had extensive experience, is so far off. The sizes of the specimens may also have posed a problem. In the case of gold and silver, we can assume that they were relatively small. Weighing them with the necessary accuracy must have been extremely difficult if not impossible (cf. Hodges (1964), pp. 208–9 and Hsia Hsiang-jung *et al.* (*1980*), p. 301.) Of course, miners had no need to deal in such precision.

pockets of higher grade ore in the darkness of a drift merely by their feel.[168] There were undoubtedly Chinese miners who shared the same ability. Unfortunately, this is an especially good example of a skill that could be developed only by miners working in the mines and was unlikely to be conveyed to outsiders, not least because it might provide the miner working especially in gold and silver mines with an opportunity to increase his income by pocketing bits of higher grade ore.

The pharmaceutical works have extensive information on the taste and odour of minerals, as one might expect from their medical focus. Taste and smell, however, played only a very small rôle in miners' efforts to identify minerals. On occasion, miners may have been led to nitre beds because of their distinctive odour[169] or to deposits of kaolin because of its earthy odour.[170] Taste was especially useful in distinguishing certain water-soluble salts, such as halite (salty), sylvite (bitter or sour) and the very important alum (drying).[171] The characteristically very sour and bitter taste of chalcanthite (copper sulphate, *shih tan* 石膽), as noted for example in the *Thang Pen Tshao* 唐本草,[172] was well-known to miners at the copper precipitation works in the Sung and they used variations in the taste to judge the quality of different waters.[173]

When considering taste, it should also not be forgotten that the tongue was a most convenient tool for miners in another way, that is, for removing dust and dirt from mineral samples so that their appearance could be analysed more accurately.[174] Of course, this practice in turn would have given the mining community good familiarity with at least that limited repertory of taste characteristics that could help in the identification of a given mineral sample.

Sonority probably played a significantly larger rôle in China as a technique for the examination of minerals than in other areas of the world. The roots of the technique go back to Neolithic times and those miners who searched for jade and other stones to be used in sets of chiming stones and who therefore paid special attention to the acoustical properties of the rocks they examined.[175] The ubiquity of chimestones in early China – stone regularly figures in listings of the four or eight main materials from which musical instruments were made[176] – undoubtedly provided an important stimulus to prospecting and mining as well as encouraging a growing empirical knowledge of rocks in general. Many passages from surviving early works, starting with the *KT*, refer to striking the jade and using the sound to determine its authenticity or quality.[177]

In later times, the pharmaceutical natural histories continue to record sound tests for identifying minerals or for distinguishing the quality of a given specimen.

[168] Todd (1967), p. 56. [169] Vol. 5, pt. 4, pp. 187–8.

[170] Mottana *et al.* (1977), p. 46. The fact that it stuck to the tongue also helped in the identification of kaolin; Anon. (*1971*), p. 26.

[171] Mottana *et al.* (1977), p. 46. [172] Lu Hsueh-shan (*1984*), p. 17. [173] Cf. below, Section (*j*)(1).

[174] Young (1969), p. 129. As Young comments: 'Indeed, the stigmata of the prospector might well have been a calloused tongue, since this organ was most prominent within his armentarium.'

[175] Rostoker *et al.* (1984), p. 750; Hsia Hsiang-jung *et al.* (*1980*), p. 424. [176] Vol. 4, pt. 1, p. 145.

[177] For a selection of these texts, cf. Hsia Hsiang-jung *et al.* (*1980*), p. 424; Lu Hsueh-shan (*1984*), pp. 5, 16. On chimestones in general, see von Falkenhausen (1993).

We have no information on which of these tests may have been used by miners. One good, if distasteful, candidate would seem to be the testing of sulphur by grinding it with the teeth. If it did not crackle, it was thought to be of good quality.[178] Similarly, one could test sulphur-bearing earth by squeezing it between the fingers: only a swishing sound like the wind indicated that the sulphur was of first quality.[179]

Miners may also have sometimes used the sound made on a touchstone to identify metals or ores. For example, Tshao Chao of the Ming, in his 'The Essential Criterial of Antiquities' (*Ko Ku Yao Lun* 格古要論) noted that gold containing copper would make a noise when rubbed on a touchstone or scratchplate (*shih shih yu sheng* 石試有聲).[180]

(vii) *Heat tests*

Although miners in traditional China could not benefit from modern chemical understanding of rocks and minerals, they nevertheless did make use of a number of simple tests that involved heat-induced chemical reactions. One group of tests relied on the fact that different minerals when introduced into a flame will colour the flame, the colour depending on the metals present. Thus, in Yunnan during the Chhing, miners used flame tests to distinguish ores from gangue, with a white flame indicating gangue, a green to blue flame ore.[181] These tests also helped them distinguish between ores and to determine the quality of ores, with a red flame considered an indicator of the highest quality ore.[182] Flame tests also helped in the distinguishing of various salts, sometimes a difficult problem. For instance, there was the problem of differentiating potassium nitrate from other salts such as sodium or magnesium sulphate. This was crucial especially for use in gunpowder because of the importance of the quality of potassium nitrate (saltpetre) in the mixture.[183] But even when the potassium nitrate was used as a flux in smelting or as an element in processes for bringing insoluble mineral into solution (Vol. 5, pt. 7, p. 96), it was important that the substance used be true potassium nitrate of reasonable purity for it to be able to perform its task effectively.[184] By the end of the +5th century, Thao Hung-ching describes the purple potassium flame of saltpetre, as well as its strong deflagration on charcoal.[185] In fact, the potassium flame test probably goes back at least to the +3rd century, which would place it among the oldest references to a flame test in any civilisation.[186]

[178] *PTKM*, ch. 11, p. 63; de Mély (1896), p. 143.

[179] *Phi Hai Chi Yu*, p. 16a; Chang Hung-chao (*1954*), p. 441; Meng Nai-chhang (*1982*), p. 587.

[180] Lu Pen-shan & Wang Ken-yuan (*1987*), p. 77. Cf. also *PTKM*, ch. 8, p. 3; de Mély (1896), p. 13. Percival David (1971, p. 134) interprets this to mean the sound made when the gold was struck against a stone. This reading, however, is undercut by the following phrase which speaks of the gold leaving grains on the touchstone.

[181] Copper oxides will colour the flame green, chlorides blue; Pearl (1973), p. 227.

[182] Yen Chung-phing (*1957*), p. 54. [183] Golas (1982), pp. 455–6. [184] Vol. 5, pt. 4, pp. 186–7.

[185] Vol. 5, pt. 7, p. 97. For a good later description (probably Thang or Sung but possibly earlier), cf. Vol. 5, pt. 4, pp. 186–7.

[186] Vol. 5, pt. 4, p. 185. In Europe, the earliest reference to a flame test, in this case to identify the purity of iron ore, seems to be that of the *Mittelalterische Hausbuch* manuscript of +1480; Smith & Gnudi (1959), p. 66, fn. Biringuccio refers to determining the quality of saltpetre 'by burning it'; *Ibid.*, p. 413.

Without use of a spectroscope, flame tests are rather crude. Yet, like so many of the other tests that were in fact most practical for use by working prospectors and miners, they had the advantage of being very simple.[187]

Another group of flame tests relied not on what happened to the flame but rather how the specimen itself reacted to heat. As early as the Eastern Han, Wei Po-yang 魏伯陽 in his *Chou I Tshan Thung Chhi* 周易參同契 (The Accordance of the Book of Changes with the Phenomena of Composite Things) noted that gold, even when subjected to firing at a high temperature, would maintain its colour and its gleam.[188] Such tests were useful for distinguishing gold from pyrite which, when roasted in a charcoal fire, not only gave off a cerulean smoke but also at sufficiently high temperatures turned black and formed flecks of iron on its surface.[189] Ko Hung 葛洪 notes in his early +4th century *Pao Phu Tzu* 抱樸子 that mica cannot be destroyed even by a blazing fire.[190] Su Sung 蘇頌 remarked in the +11th century that arseno-pyrite could be distinguished from white gypsum (*wang li shih* 王里石) because the latter would burn into ash on heating while the former would only break up.[191] Chinese tin miners in 19th century Malaysia knew that the tin ore cassiterite could be distinguished from the virtually identically appearing zircon because the colour of the cassiterite would not be affected by heat up to 1000 °C while the brownish zircon would turn colourless.[192] Chinese miners in traditional times were also undoubtedly aware of the garlic smell emitted by arsenic ores when heated.

(6) The Limits of Traditional Prospecting Knowledge and Techniques

We have discussed at some length above (Section (*c*)) the limited value for working miners of most traditional theorising about minerals. In particular, we noted the tendency of the alchemists and pharmacologists who did most of this theorising to focus on highly generalised and arbitrary theories explaining how minerals came to be rather than where they were likely to be found. Their theories also gravitated to anthropological and agricultural analogies that, as often as not, were misleading rather than helpful. Finally, they seldom tested their ideas by careful observation of the phenomena they purported to explain.

It would be wrong, however, to conclude that theories or, perhaps more accurately, widely accepted general ideas about minerals exercised no influence at all on mining practice. For example, in the Yunnan copper mines, the miners apparently

[187] The modern descendant of the early flame tests, the blowpipe test, is still recognised as one of the most useful tests for rapidly identifying minerals in the field. Of course, flame tests constitute only a small part of the range of tests that are now performed by means of a blowpipe; see Pearl (1973), pp. 224ff.

[188] Cited in Lu Pen-shan & Wang Ken-yuan (*1987*), p. 79. Below 1063 °C, gold will neither melt nor change colour.

[189] Lu Pen-shan & Wang Ken-yuan (*1987*), p. 79, citing Ku Thai's *Po Wu Yao Lan*, but, following a common misattribution, giving Ku Ying-thai as the author; cf. Hummel (1943), Vol. 1, p. 426.

[190] Ch. 11, p. 8b, cited in Vol. 3, p. 647 (trans. in Feifel (1946), p. 16).

[191] Ho Ping-yü (1968), p. 166.

[192] United Nations (1972), p. 38, fn. 37.

believed that the natural native copper (*thien sheng thung* 天生銅) found in the cracks of the rock was the 'mother' of copper and should not be removed.[193] What we have here is an example of an organic analogy used to explain the appearance of minerals. Minerals 'grow' in the earth not as a result of physical processes such as deposition but rather much as a plant grows from a seed or many animals grow inside their mothers.

There was another theoretical perspective that was shared by miners probably because it accounted for one of the great frustrations of underground mining. Yunnan miners generally believed that water in a mine was a good sign of extensive, high-quality deposits because 'metal and water mutually produce each other' (*chin shui hsiang sheng* 金水相生).[194] In fact, the association of water and rich deposits of copper has a good scientific basis: many rich copper deposits are found in the so-called zones of secondary enrichment that lie just below the water table (cf. above, Section (*d*)(2)(ii)).[195] Though Chinese miners could not have understood the cause of the association between water and rich deposits, recognition of it perhaps gave them some comfort as they struggled with what was one of the curses of the underground miner.[196]

For the most part, however, Chinese prospectors would find little of use in what was written in books about the location of ore deposits. Their prospecting is better seen as a kind of 'informed guesswork', supplemented by plenty of hard work and persistence. Michael Fores makes a similar point about even contemporary engineering: 'Engineering is not primarily to do with what is said in books. The process of most engineering work is not observed, set down on paper and recorded for others to read about; the knowledge used by engineers in the course of their work is characteristically informal and unrecorded . . .'[197] Another parallel can be seen in agriculture where 'theory is still very far removed from practice' and even laboratory results are far from infallible predictors of what will happen in the field.[198] Contemporary geological understanding of ore deposits certainly helps to predict where ore deposits *may* appear. Even now, however, theory can hardly be counted on to tell where they *will* appear. As Otis E. Young puts it in what he calls the 'greatest of all rules' of mineralisation: 'mineralisation will probably *not* be in certain places; it *may* be in others; it *will* be only where it is indisputably found, and nowhere else.'[199]

[193] Yen Chung-phing (*1957*), p. 53. [194] Li Chung-chün (*1982*), p. 3; Yen Chung-phing (*1957*), p. 59.

[195] I am grateful to Lung Tshun-ni of the Industrial Technology Research Institute in Taiwan for this suggestion. It was a point well understood by European miners at least by the +16th century, as seen in the words of Biringuccio: '. . . I had always understood that water was the primary and peculiar companion of minerals . . .' from which he drew the unwarranted conclusion that 'all mountains from which abundant waters spring also abound in minerals'; Smith & Gnudi (1959), pp. 20–1.

[196] Cf. Section (*h*)(11) below. [197] Fores (1981), p. 126.

[198] As noted by Francesca Bray in Vol. 6, pt. 2, p. xxiv.

[199] Young (1970), p. 8. Eastern Shantung provides a particularly vivid example of an area in China that offered much less in the way of certain deposits than its rock formations seemed to suggest. As H. M. Becher noted in 1887: 'In eastern Shantung there are rock formations that look as if they would be productive of metals but are not. Examples include gneiss similar to the normal gneiss which had rich silver lodes of the Saxon Erzgebirge; granite which often carries gold or tin; crystalline schists and limestones which are often the country rock of lead, copper, iron and other metalliferous ores. All of these are disappointing here.' Becher (1887), p. 29.

While recognising then the limitations imposed on traditional prospecting by inadequate geological and mineralogical understanding, we should not exaggerate the extent to which the absence of such knowledge hindered prospecting by Chinese miners. As late as the 1920s, many Chinese tin prospectors were very confident that their intuition and experience put them on a par with foreign engineers and their science![200] We should also perhaps modify the statement made above that '[w]ithout knowledge of the chemistry of rocks, the search for minerals could never have been put upon a rational basis.'[201] Rational here might better read 'scientific'. The most skilled prospectors and miners in traditional China actually had quite an inventory of practical knowledge and techniques that allowed them to prospect 'rationally' and often even quite effectively.

[200] Jarland (1921), p. 375. [201] Vol. 3, p. 673, fn. g.

(g) PLACER AND SURFACE MINING

In China as elsewhere, the first steps toward mining long pre-date the appearance of *Homo sapiens*. Apes and other animals sometimes discovered how to use stones for simple tasks, such as crushing nuts or shells, or as weapons (usually without modifying their shape or dimensions).[1] The distant ancestors of modern humans carried this discovery further by seeking out with greater care those stones whose hardness or shape lent them particularly well to certain uses. Moreover, as something like human thinking and sensibility began to emerge, certain stones came to be highly appreciated for their beauty or for their supposed numinous qualities.

In this early period, with desirable rocks abundant at the earth's surface and little or no digging needed to gather them, we are still at a pre-mining stage perhaps best thought of as 'grubbing' since it had far more in common with grubbing for nuts, tubers and the like than with the kinds of excavation we associate with mining. But this long experience of selecting rocks appropriate for different purposes[2] certainly nourished the motivation that would lead to true mining, as well as honing the ability to distinguish between more and less useful rocks.

The early Chinese experiments with a wide variety of rocks testify to a pronounced willingness to explore a broad range of available natural resources. They may also reflect the relative shortage of rocks such as flint, chert and obsidian that were so important as tool materials in other primitive societies because of the ease with which they could be shaped by flaking.[3] In China, for the most part, other rocks had to be found to take their place.[4] This search for usable rocks led by one route to placer mining, by another first to open-pit mining and quarrying, and then to true underground mining.[5]

[1] Cheng Te-khun (1959), p. 19.

[2] Few if any kinds of stones were not experimented with at one time or another. Leakey (1954), p. 129.

[3] Although a major site for producing flint tools has been discovered in the area of Huhehot (Hu-ho-hao-the 呼和浩特) in Inner Mongolia (Su Jung-yü *et al.* (1995), p. 25), we have no evidence in China of deposits of flint comparable to that of Rijckholt in the Netherlands whose estimated 41,000 cu. m of excavated flint nodules could have provided sufficient material for 153 million axe heads! Shepherd (1980), p. 167. For two other fairly substantial deposits of flint, see Reid (1901–1902), p. 27 (over Honan coalfields) and von Richthofen (1871), p. 14 (at Chi-chou 雞頭 on the Yangtze between Han-khou and Chiu-chiang). There was also chert present in the limestone of southwest Manchuria, but it was not a good tool material; chalcedony found in the cavities of lava rocks in the same area, on the other hand, was; Andersson (1934), p. 192.

[4] Chang Kwang-chih (1977), pp. 41, 45, 54–5. The remarkable capacity of the Chinese for tedious processing of materials, as seen later for example in the carving of jade, may have been encouraged from earliest times by their relatively greater reliance on quartzite. Flint and chert are brittle so that they can be chipped or flaked quite easily; they also fracture in such a way as to give sharp edges. Quartzite, on the other hand, is both very hard and also very resistent. In early periods, it could be shaped only by labouriously hammering its surface; Hodges (1970), p. 98. Among the seven earliest stone tools found in China (in Yunnan), four are scrapers made of quartzite; Su Jung-yü *et al.* (1995), p. 25.

[5] For an interesting recent discussion of the contributions not only of the Pre-metal Age lithic industry but also other industries such as ceramics to early mining and metallurgy, see Barnard (1989), pp. 145–52. Underground mining was perhaps encouraged by techniques developed for digging wells, a practice that originated in south China by about the −4th millenium and in the north during the Lung-shan 龍山 period (c. −2000); see Fang Yu-sheng (*1986*) and Shih Chia & Kho Shui (*1987*).

(1) Placer Mining

(i) *Placer deposits and their mining*

Placer mining boasts arguably the longest history of any human technology. Its origins go back in a straight line to the discovery by proto-humans that river and stream beds were especially good sources of useful stones. Flints, quartzites and schists that had survived the rolling and battering of river waters were likely to be tough as well as resistant to corrosion, and therefore ideally suited for use as tools.[6] Cheng Te-khun claims, without a source, that the inhabitants of what is now southern Shansi were searching in this way mostly for quartzite pebbles some 600,000 years ago.[7]

Besides learning to recognise those hard rocks and pebbles that could be used for implements, early proto-humans could hardly have failed to note other 'rocks' that, because of their softness and malleability, were singularly *un*suited for most uses as implements and tools. They might be very useful, however, for special purposes. Native copper, for example, was difficult to work in nodule form but could be transformed relatively easily into blades when it appeared in thin plates.[8] Moreover, because of their colour or glitter, gold and copper both invited use as ornaments.[9]

True placer mining begins, however, with efforts to obtain minerals in the form of very small particles, some even at first invisible. Such deposits result from the fact that mineral-bearing rocks at or near the surface of the earth are subject to weathering which leads to erosion and disintegration. These detrital materials can then be transported quite easily by water, wind, glaciers or gravity. Materials that are transported mainly by water and collect in river beds, pools, lakes, deltas or the like, are known as alluvial deposits. Detrital materials that collect relatively close to their point of formation, as on the slopes below an outcrop, are called eluvial deposits, or float. Both groups together constitute placers or placer deposits.[10]

Only resistant, non-weathering minerals will be found in placer deposits since they are not subject to oxidation and to the action of the atmosphere.[11] In China, only gold, tinstone (cassiterite), magnetite (an iron ore), native copper and some precious or semi-precious stones constituted important placer deposits. Of these, gold was far and away the most important, followed by magnetite and cassiterite.[12]

The mining of placers is one of the easiest of all mining operations. In the first place, not all eroded materials are transported at the same rate. Mineral-bearing materials, typically heavier than other materials, tend to be concentrated in the placers after many of the lighter materials have been transported farther downstream or

[6] Rosenfield (1965), p. 195. [7] Cheng Te-khun (1966), pp. 3–4. [8] Forbes (1954), p. 585.

[9] As noted above (Section (*e*)), nuggets of gold and pieces of native copper, even of considerable size, were far more abundant in early times than they are today.

[10] Cf. above, Section (*d*)(2)(ii); Stoček (1958), Vol. 1, pp. 53–4; United Nations (1972), p. 44.

[11] Stoček (1958), Vol. 1, p. 54.

[12] Much placer mining has been and continues to be carried on in China. We can also assume that, especially in early times, there were many placer deposits that were eventually exhausted and forgotten. Hoover & Hoover (1912), p. 412, fn. For the history and present situation of the exploitation of ironsands, cf. Wagner (1985), pp. 28–32.

downslope. The result of this natural process of concentration is that minerals that originate in primary deposits where their occurrence is too minute for the deposit to be economically workable may come together in these secondary deposits to form workable or even relatively rich placers.[13]

A second reason why placers are relatively easy to mine has to do with the results of what we might call nature's milling (or crushing). Placer deposits normally consist of uncemented or unconsolidated gravels, sands and clay, or residues, making unnecessary the breaking of rock that requires much time and effort in underground mining operations.[14] The minerals can be obtained by relatively simple and inexpensive processes that separate them from the unwanted materials. Moreover, placer deposits are normally surface or shallow deposits, requiring little excavation. Consequently, though the mineral content of placers may be small, ease of working will often encourage their exploitation.[15] There are, however, cases where surface placers have later been covered by overburden, sometimes to a great depth. In the case of such buried placers or 'deep leads' with their deposits of cassiterite in Yunnan, getting at the deposits was not especially difficult because they still lay well above the water table. In Hopeh, however, the covering gravel could be up to 100 m thick. That, and problems with water, prevented the Chinese from reaching the layers just above the bedrock where the highest concentrations of placers are often to be found.[16]

(ii) *Gravity separation techniques*

Learning to use water in a 'washing' process to separate minerals from their surrounding matrix constituted a major step forward from dry grubbing and opened the way to placer mining on a significant scale. Often this was the only way to obtain the tiny particles that are typically the object of the placer miner's efforts. Certain deposits, especially those characterised by cohesive, clayey soils, were very difficult if not impossible to work by grubbing. Water, however, could be used in a puddling process to convert clay into a more fluid form that could then be bailed away. The remaining material, perhaps after drying, could be picked over or, in later times, panned.[17]

Nature must have provided the important clue here. The potentially useful rôle of water could have been noticed any time it flowed into a previously worked dry

[13] Tegengren (1924), p. 179. In practice, however, the mineral content of placers is generally small; Stočes (1958), Vol. 1, p. 54.

[14] United Nations (1972), p. 44.

[15] Stočes (1958), Vol. 1, p. 54. For example, in Chekiang, ironsands that consisted only of a very low 5–6% iron were worked not only because the sands were easy to collect but also because they could be easily washed to produce a concentrate of 45–50% magnetite; Tegengren (1924), p. 255. In Hupeh in the 1950s, river sand with 2–7% ironsand contained 61–63% iron (corresponding to 84–87% magnetite) after only one sluicing; Wagner (1985), p. 52. In southern Henan it was said in 1958 that sluicing ironsand was the principal sideline activity of the peasants and '[p]ractically all the peasants . . . , young or old, male or female, know how to sluice iron sand'; Wagner (1985), p. 8.

[16] Hoover (1899–1900), pp. 327–9. [17] Young (1970), p. 59.

deposit or even down a mountainside, washed away some soil or sand, and thereby revealed previously unseen mineral deposits. Under proper circumstances, placer mining came to resemble a 'harvesting' operation, with a new 'crop' each year.[18] In +18th century Taiwan, for example, there was at least one area where the natives relied on heavy eighth-month rains to erode part of the mountainside, collecting the eroded soil as well as water in receiving pits dug specifically for that purpose at the foot of the mountain, and then washing the soil for gold.[19] A much earlier account from the Thang, the +9th century *Man Shu* 蠻書 (Book of the Barbarians) of Fan Chho 樊綽, provides a more detailed description of natives in Yunnan using a trenching process to obtain native gold (*sheng chin* 生金):[20]

In the period between spring and winter, they first dig [receiving] pits (*kheng* 坑) a *chang* 丈 or more deep (three or more m) and several tens of *pu* 步 across (one *pu* = c. 1½ m). In the summer months, when the rain comes down in torrents, it carries mud into the pits. The natives then spread out this alluvium and pick over the sand and rock [for gold] (*chi yü thien thu chih so sha shih chung phi chien* 即于添土之所沙石中披揀). They may get flakes or nuggets. The larger nuggets weigh up to one or two *chin* (c. 500–100 grams). The smaller pieces weigh three to five *liang* (c. 100–200 grams).

Also from the Thang comes another example of a 'harvesting' kind of mining that supposedly occurred at a certain 'Gold Pond' (*chin chhih* 金池) near present-day Canton.[21] Peasants there raised ducks and geese in great numbers and carefully washed their faeces for gold flakes they had presumably ingested when drinking the gold-bearing water. Successful peasants were reputed to be able to recover between a half-ounce and an ounce of gold per day.[22] Sung Ying-hsing, in his *TKKW*, considers this story as probably apocryphal (*khung wang chi* 恐妄紀) but Hsia Hsiang-jung, Li Chung-yun and Wang Ken-yuan accept its authenticity.[23]

Most processes using water to separate placer minerals from their matrix rely on the differing specific gravities of the minerals and of the unwanted gangue in which they are contained. The average acidic (i.e., light-coloured, siliceous) gangue is little more than two and one-half to four times as heavy as water while desired minerals are much heavier. Gold, with the highest specific gravity of all minerals, is more than 19 times as heavy as water.[24]

The simplest method for separating the heavier minerals from their lighter sand or gravel or clay or crushed rock matrix is by panning or washing (*thao hsuan* 淘選).

[18] Placer mining was thus the one area of mining where its 'wasting' character could be counteracted by processes of replacement, provided the placering was practised on a small enough scale. This was the case for example in the gold placers of the Han River 韓江 in Hupeh. Each year the waters brought down new gold to replace what had been taken out in previous mining. As von Richthofen noted in the 1870s, however, any mechanised process to work the gravels on a more extensive scale would have soon destroyed the deposits; von Richthofen (1874), p. 4.

[19] Lin Chhao-chhi (*1969*), p. 103; Davidson (1903), p. 463.

[20] *Man Shu*, ch. 7, cited in Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 268; my translation, assisted by Luce & Oey (1961), pp. 70–1; cf. also Yoshida (*1967*), pp. 236–7.

[21] *Ling Piao Lu I, shang*; cited in Hsia Hsiang-jung *et al.* (*1980*), p. 298, fn. 4.

[22] Schafer (1963), p. 251.

[23] *TKKW*, ch. 14, p. 234; Sun & Sun (1966), p. 236; Hsia Hsiang-jung *et al.* (*1980*), p. 288. Sung also notes that miners sometimes stole gold by swallowing it.

[24] Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 267; Young (1970), p. 58.

Most typically, the gravel is swirled in a wide, usually flattish dish or pan.[25] This causes the heavy particles to settle to the bottom while the lighter materials remain suspended in the water and can be allowed to flow off with the water over the edge of the pan. The process can be used not only for separating minerals such as gold, copper, iron and tin from the sands and gravels of placer deposits but also for isolating native minerals embedded in hard rock by first crushing the rock and then panning it.[26]

We do not know when the process of panning was discovered. It is hardly likely to have occurred much before the late Neolithic period since the very small particles normally found in panning would be of little use before it had been discovered that small bits of metal could be combined by melting to form a larger piece, something probably not known before then.[27]

The earliest washing pans or bateas so far discovered in China come from the Thung-lü shan 銅綠山 excavations. Of the three that have been illustrated (Fig. 30) in the excavation reports and other discussions of the site, two are identified as dating from the Spring and Autumn period (c. –7th and –6th centuries), the third from the Warring States period (–480 to –221). Interestingly, they reveal three quite different shapes, suggesting that the miners experimented to find what shapes would be most effective. Such experimenting must have continued at least on a small scale since, at some point between the late Warring States period and the Ming, a quite different washing implement (though still made of wood, and presently called a *po chi* 簸箕) (Fig. 15) came into use, with a bottom consisting of two pieces of wood that come together at an angle, forming a trough.[28] In some mining operations, this triangular box (unique to Chinese mining?) was used for a final stage of washing (Fig. 31) after a preliminary washing in some kind of sluice (cf. below).[29]

It was in the various techniques of washing ore that, more than in most areas of mining, human manual skill was the key ingredient.[30] For instance, miners who were used to washing lode tin, which tended to be quite angular, would need some practice before they could equally effectively wash the more rounded alluvial or

[25] As we shall see, the three basic actions that can accomplish this separation are swirling, reciprocal shaking and vertical agitation.

[26] This technique has been important not only for production but also as a means by which prospectors could assay the quality of hard rock deposits. They would simply crush a sample of a prospective deposit and then pan the results to estimate the richness of the ore.

[27] In addition, melting metals together is sometimes more difficult than one might expect, as Tylecote has pointed out for the case of fine particles of gold; Tylecote (1992), p. 5.

[28] Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 268. I have found no early use of the term *po chi* to designate this washing device, which we shall refer to as a 'washing box'. (One would not want to call it a 'batea' because bateas are usually made from one piece of wood, resemble in at least a general way a pan or dish, and are shallow; Fay (1920), p. 68.)

[29] *Shu Yuan Tsa Chi*, ch. 14, p. 9a; Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 270–1. What looks to be a 'streamlined' version (Fig. 32) seems to have been used by silver miners in Mongolia in the 19th century, but this is the only illustration of it I have found. Chinese miners also used closely woven bamboo baskets for washing (Fig. 98) though this was a very wasteful implement when dealing with finely disseminated ore; Brown (1923), pp. 144–5.

[30] Along with patience. 'In alluvial-gold washing the Chinese is second to none. He has a maximum of patience and requires a minimum of remuneration.' Reid (1901–1902), p. 36.

Fig. 30. Wooden washing pans (bateas) from Thung-lü shan 銅綠山. (*a*) Round pan (*phan* 盤): Spring and Autumn Period (Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 269). (*b*) Rectangular pan (*thao chhih* 淘池): Spring and Autumn Period (*Ibid.*, p. 270; Lu Mao-tshun (*1974*), pl. 8). (*c*) Boat-shaped pan: Warring States Period, 35 cm. long (Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 269; Anon. (*1975*), pl. 5).

placer tin.[31] When the panner is expert at his task, however, astonishing results can be achieved, especially when dealing with a very heavy mineral like gold. Richard Pearl relates a championship performance in which a 75-year-old panner was able to recove all 20 pinhead-sized flakes of gold from one tonne of crushed rock in less than twenty minutes![32] Not surprisingly, given the patience and manual dexterity that have marked so much of Chinese handicraft production, the skill of Chinese panners drew the admiration of those Westerners who took time to look closely at their work. As Baron von Richthofen commented in regard to the gold panners along the Han River 韓江 in Hupeh: 'In the handling of the pan the Chinese of this country have acquired a skill that would excite the envy of a practised California gold-digger.'[33]

[31] Collins (1909–1910), p. 205, comment by O. J. Steinhort.
[32] Pearl (1973), p. 113. [33] von Richthofen (1874), p. 4.

Fig. 31. A miner at Thao-hua 桃花 in Kwangsi demonstrates the washing of gold with the wooden 'box' that has been used by Chinese miners for at least four centuries (cf. above, Fig. 15). Original photo, 1994.

Fig. 32. A 'streamlined' washing pan used by miners in Mongolia. Woo (1902), p. 757.

Fig. 33. Miner in Montana, USA washing gold-bearing sand and gravel; Sloane & Sloane (1970), p. 19.

But whatever the shape of the washing pan, whatever the skill of the panner, panning is a wearisome task. This lends particular interest to the fact that, in contrast to the predominance of metal (tin and, especially, iron) washing pans in recent centuries in the West, the Chinese seem to have had a clear preference for wooden devices. In part this may have been due to the cost of metal pans. On the other hand, it may also have been because of a slight difference in panning techniques. While panners in the West frequently swirled their pans with the top edge at most barely submerged in the water (Fig. 33),[34] the Chinese seem to have taken advantage of the buoyancy of water to help support the weight of the box and its contents,

[34] Young (1970), p. 109 and fig. 30.

allowing the box to float on the water[35] and thus easing strain on the back, shoulders and arms of the panner.[36]

An even better solution to the rigours of panning ore was to use sluicing instead of or in addition to panning. Provided there is an adequate source of water, one can set up an inclined trough of some kind (a sluice), put the ore-bearing dirt or gravel in the sluice, and allow water to flow over it in a continuous stream. While the lighter gangue flows off, heavier particles will tend to sink to the bottom of the sluice where they can later be collected and either picked over or washed in order to select out the desired mineral or ore.

The earliest sluices, drawing on the example provided by nature, may well have been simply inclined trenches dug in the earth. These would have certain disadvantages, however. In many cases, collection of the particles that had been deposited must have been very clumsy, requiring the scraping up of at least a small amount of the earth at the bottom of the trench in order to be sure to get as many as possible of the particles present. This would mean extra washing of non-paying dirt. In some cases, it would also presumably cause increasing deepening of the trenches over time, rendering them harder to use until eventually they would have to be abandoned. Still another serious limitation was the inability to adjust the angle of the trench to regulate the velocity of the water flow in order to compensate for different kinds of wash-dirt.

Excavations of early copper mines have unearthed evidence that suggests that Chinese miners may have begun constructing and using wooden sluices as early as the Western Chou (–11th to –8th centuries). At the Thung-ling 銅嶺 mines in Jui-chhang 瑞昌, a 3.43 metre long wooden trough carved from a log and fitted with a removable crossboard at each end and dating perhaps to that period has been judged by excavators to have been a sluice through which the flow of water was controlled by the crosspieces.[37] At the Thung-lü shan 銅綠山 mine, five wooden troughs, varying in length from 65 to 260 cm, have been found (Fig. 100). In contrast to the opinion of the original investigators that these were simply troughs for getting rid of mine waters, Lu Pen-shan, Wang Ken-yuan and other experts on early Chinese mining have concluded more recently, apparently on the basis of gashes found in at least one trough, that these actually were sluices for ore separation.[38]

One hesitates on the basis of the descriptions in the reports to give unqualified acceptance to the idea that these troughs were indeed used as sluices.[39] If they were, it may well be that Chinese miners in a very early period not only discovered how to use sluices for mineral separation but were also working, by means of gashes, toward a solution to the problem of recovering lighter mineral particles that either fail to sink all the way to the bottom of the sluice or, having done so, are later washed away by the flow of water.

[35] Wu Yang-tsang (1902), p. 757.

[36] My own brief experimenting with a wooden panning device at the Thao-hua 桃花 gold mines in Kwangsi confirmed that the device did have, as expected, considerable buoyancy.

[37] Chou Wei-chien *et al.* (*1990*), p. 20. [38] Anon. (*1975*), p. 8; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 267.

[39] There do not seem to be any reports of radiocarbon dates for these troughs.

Fig. 34. Miner preparing a wooden sluice box for washing gold by scraping gashes in the board to serve as riffles. Thao-hua 桃花, Kwangsi. Original photo, 1994.

These gashes are a primitive form of 'riffles', the term commonly used for crosswise obstructions on the bottom of a sluice designed to trap the heavier mineral particles. The first clear textual reference to the use of this technique in China dates from over a thousand years later, toward the end of the Northern Sung. In the *Phing-chou Kho Than* 萍州可談 of Chu Yü 朱彧 (+1075? to after +1119), we read:[40]

To obtain gold in Szechwan, they collect sand along riverbanks and wash it in a wooden pan (*mu phan* 木盤). A great deal of effort is expended for a meagre return. In Teng(-chou) 登州 and Lai(-chou) 萊州 [along the northern coast of present-day Shantung], the miners use only a large piece of wood that has been hollowed out, leaving blademarks [on the bottom to serve as riffles]. They place the gravel at the top [of the inclined sluice] and pour water over it, causing the sand to flow away while the gold [particles] collect in the gashes where they are very easy to recover. (Fig. 34)

That the Shantung area was by far the most important region for the washing of gold in the Northern Sung was undoubtedly due in part to the use of sluices with riffles.[41] But riffles were not the only means to assist sluice concentration and

[40] Ch. 2, p. 14b.

[41] *SHY:SH* 34, 14a [1026]; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 267. In the Chhing period, sluices (*chin chhuang* 金床) were in widespread use in Yunnan where the government levied a tax of one *chhien* 錢 (3.73 grams) of gold on each sluice per month; Chang Hung-chao (*1954*), p. 215, citing the *Yun-nan Thung Chih*. In Heilungkiang, the current term for sluice is *chin liu tzu* 金溜子 and, for riffles, *liu ko tzu* 溜格子; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 270.

Fig. 35. A sluice board covered with a piece of cloth about the thickness of a towel to substitute for riffles in the sluicing of gold. Thao-hua 桃花 in Kwangsi. Original photo, 1994.

recovery of metal particles. Another technique, as old as Jason and the Golden Fleece, relied on an animal hide or a piece of cloth placed on the surface of the sluice. The rough texture trapped the metal particles, which were then recovered by burning or washing the material. The earliest reference to using some kind of cloth at the bottom of the sluice seems to come from the +8th century *Pen Tshao Shih I* which speaks of obtaining 'bran gold' (*fu chin* 麩金, i.e. fine gold particles) by washing it on felt (*chan shang thao chhü* 氈上淘取)[42] and it is still widely used by Chinese miners (Fig. 35).

In most cases where gashes or riffles are used instead of a cloth to trap the particles, the sluicing process will produce not isolated particles that can be relatively easily collected but rather an enriched mud that must then be panned to separate out the particles (Fig. 36 and Fig. 37).[43] Something of an intermediary between wooden slot riffles and the use of cloth was to be found at least in some gold washing operations in Yunnan during the Chhing. There, instead of wood slots, the miners used split lengths of bamboo. The rough interior of the bamboo functioned like cloth to catch gold particles.[44]

[42] Cited in Huang Yü-heng & Ai Ta-chheng (*1989*), p. 74; see also Schafer (1963), p. 251.
[43] Another way to achieve the effect of riffles was to use rocks in the sluice (Fig. 37).
[44] Moore-Bennet (1915), p. 224.

Fig. 36. A miner collecting enriched mud from a sluice to pan it in a washing box where the actual particles of gold will be separated out or the mud will be further concentrated. Thao-hua 桃花 in Kwangsi. Original photo, 1994.

(a) (b) (c)

Fig. 37. Rock riffles at a gold mine in Thao-hua 桃花, Kwangsi. (*a*) The rocks are neatly placed in the sluice, here made of concrete, and the gold-bearing water is allowed to run down. Every eight to twelve hours, the flow of water is cut off and the rocks removed. After a check for any larger nuggets present (*b*), the gold-bearing mud or sand is carefully collected (*c*) either to be first concentrated by washing and then amalgamated with mercury (Fig. 14) or immediately amalgamated. This process demonstrates vividly the labour-intensive character of so much of Chinese mining as well as the dangers that miners often face, in this case, mercury poisoning. Original photos, 1994.

A notable improvement in the efficiency of sluices with riffles (riffle boxes) could be achieved by transforming them into cradles or rockers. The American version of the cradle was perhaps invented in California by a certain Alexander Stephens.[45] Otis Young describes its construction and use:[46]

In principle, the cradle was an abbreviated riffle box mounted upon transverse rockers. Atop one end was a removable hopper equipped with some sort of mesh screen or perforated iron 'riddle' of punched plate. A slanting canvas apron ran from the 'low' side of the hopper down to the 'high' side of the riffle box. While two men dug, the third dumped the pay sand into the hopper, following it with buckets of water, as the fourth partner vigorously worked the rocker handle to and fro. The riddle scalped off the gravel, while the water and agitation worked the sands down the apron, over the riffle bars, and out the end of the cradle. From time to time the hopper was lifted, and its accumulation of gravel was dumped to one side. At appropriate intervals the canvas apron (which acted as a sort of catch blanket) was washed out, and the riffle bars were cleaned with a horn spoon. It was a crude device, but it worked, and even an unskilled ribbon clerk would cobble a rocker together in short order. It eliminated squatting haunch-deep in icy mountain streams for hours on end, as panning had required.

The earliest piece of evidence clearly suggesting that rockers may have been independently invented in China comes from a travel account published in 1862 in which Thomas Blakiston describes the rockers used at that time for gold washing on the upper Yangtze: 'The cradle or rocker is simply a shallow wicker basket resting on a frame that has a joint [?], and allows of an oscillating motion to and from the washer . . .'.[47] What Blakiston describes seems to be exactly the same device still widely used for ore or native metal washing today (Fig. 38 and Fig. 39).[48] As observed by him, the cradle was operated by one man who formed a team with four others: two to bring sand and gravel for washing, one to bring water, and one to collect the washed sand and pick over the shingle (gravel and pebbles). The form of the cradle (as best we can make it out), the date, and the location all suggest that this was probably a Chinese invention. By contrast, the cradles that appear at placer deposits in Taiwan in the late 19th century (Fig. 40) were most probably introduced by Chinese returned from the goldfields of California and Australia.[49]

Traditional gravity separation is an inherently inefficient technique, usually capturing only about half of the potential metal.[50] Only larger or 'dimensional' flecks of metal will sink to the bottom of the pan or be trapped in riffles; the very fine

[45] Young (1970), p. 110. Could he have been inspired by having seen Chinese miners using something similar?

[46] Young (1970), p. 113. [47] Blakiston (*1862*), p. 159.

[48] For an idealised and unrealistic illustration, showing both the rocking and the pouring of the water being accomplished by a single (very muscular) miner, see Hsia Hsiang-jung *et al.* (*1980*), p. 195.

[49] Davidson (1903), pp. 464, 473. Until the late 1870s, most of the Chinese who had come to the western United States were engaged in working placer mines, using the same simple techniques that had been developed in China; Lingenfelder (1974), p. 3; Paul (1963), p. 95. For a description and illustration, neither very satisfactory, of rockers currently used in China, cf. Lu Pen-shan & Wang Ken-yuan (*1987a*), pp. 269–70.

[50] According to an estimate made at the Han-ta-chhi 罕達氣 placer works in Heilungkiang, the maximum efficiency of traditional Chinese wooden sluice boxes was 70%; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 270.

Fig. 38. Contemporary miners using a 'basket rocker' at Thao-hua 桃花 in Kwangsi. Original photo, 1994. Cf. Hsia Hsiang-jung *et al.* (*1980*), p. 195.

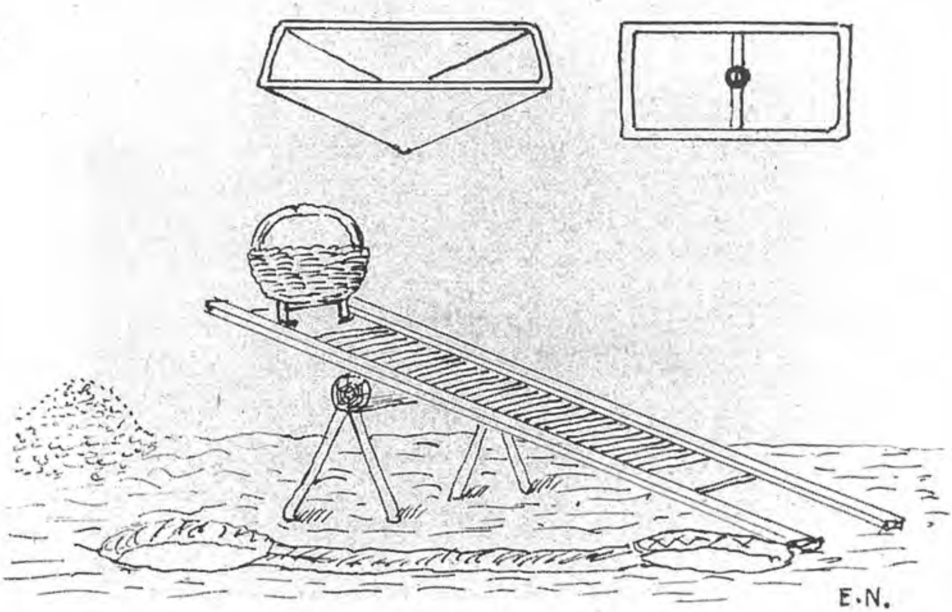


Fig. 39. A drawing of a 'basket rocker' by Eric Nyström, unidentified as to place and date. Presumably shows that this washing device was also used in north China, the main area of Nyström's work, by the beginning of the 20th century. (Since Nyström also worked for a time in Hunan [Wang Hongzhen *et al.* (1991), p. 87], the drawing may just possibly have been made there.) The construction seems to be essentially the same as the Kwangsi version (Fig. 38) though with a steeper angle to the sluice. The two pits in the foreground, connected by a trench, probably served to recirculate the water. (Note also the Chinese style triangular washing box which apparently was used not only in the south but also in north China; cf. Fig. 15, Fig. 31 and Fig. 36.) Erik Nyström archives, Östasiatiska Museet (Museum of Far Eastern Antiquities), Stockholm.

so-called flood or flour will escape in the water. Many methods involving a variety of materials have been tried to trap as much gold as possible before it was washed away. The legend of the Golden Fleece probably refers to the use of raw sheep fleece where the wool and lanolin trapped gold particles that could later be recovered by washing the fleece.[51] We have seen that felt was similarly used in Thang China. In the case of gold, the overwhelmingly dominant object of placer mining in China, the use of mercury in the washing process has been the most effective solution to this problem. If the gold-bearing water is made to flow over a pool or film of mercury, the mercury will seize and amalgamate with particles, however small, that come into physical contact with it. Only this combination of gravity separation

[51] Young (1970), p. 57.

Fig. 40. A Chinese family washing gold in the Keelung 基隆 River, Taiwan at the end of the 19th century. They are using a 'washing cradle' introduced into Taiwan some years earlier, according to Davidson, by Chinese who had learned to use cradles in the goldfields of California and Australia. Davidson (1903), pp. 464, 468, 473. This is entirely possible since most if not all indigenous rockers made use of a basket shaken in a forward–backward motion relative to the sluice (Fig. 38 and Fig. 39) while this photograph illustrates the side-to-side rocking of the sluice itself (hence the name 'cradle') which was very common in Californian and Australian goldfields in the 19th century.

and amalgamation can lead to the capture of most of the gold particles in a given deposit.[52]

We have suggested above (Section (*e*)(1)(vii)) that mercury may have been known by the Chinese as early as the Spring and Autumn period and was surely widely available by the end of the Warring States period. There is a good chance that it was in gold plating that the Chinese first made use of the amalgamating properties of mercury. Numerous excavated objects from the Warring States period have been gold-plated by a process in which gold was mixed with mercury, the resulting liquid or paste was applied to a metal surface, and the object was then heated to volatilise the mercury, leaving behind the gold plating.[53] Written references to amalgamation survive at least from the Han (Vol. 5, pt. 2, p. 243) and Ho and Needham have identified a number of amalgamation processes involving not only gold and silver but also copper, tin, iron, zinc and lead described in the *Tshan Thung Chhi Wu Hsiang Lei Pi Yao* 參同契五相類秘要 (Arcane Essentials of the Similarities and Categories of

[52] Young (1970), p. 96. Even with this technique, certain ores such as gold tellurides (black gold) or rusty gold particles with films of iron silicates or manganese would not be captured by the mercury; see Young (1970), p. 98, which also stresses the necessity of absolutely avoiding any presence of oil or grease.

[53] Chao Khuang-hua (*1984*), p. 11.

the Five (Substances) in the *Kinship of the Three*), a work probably compiled between the +3rd and +7th centuries.[54] None of this, however, gives us much of an idea of when mercury first began to be used as an aid to the more effective recovery of gold or silver particles from a sandy or gravelly matrix.

On occasion, when water was not available, minerals could be separated from their gangue by crushing the ore very fine and then using a process of air winnowing similar to that used in agriculture.[55] The fine ore would be tossed in the air from a blanket or similar cloth, and separation would be achieved by relying on the faster fall of the heavier mineral. Such a process was in use early in this century in the foothills of the Altai range in Sinkiang where the miners obtained gold by winnowing auriferous sand.[56] The process, however, is basically slow and wasteful[57] and, judging from what seems to be a complete silence in the traditional texts, was seldom if ever used in most parts of China where water would be available at least for part of the year.

(2) Other Forms of Surface Mining[58]

Apart from placer mining, surface mining can refer to a variety of methods by which miners, colliers, potters, quarrymen, builders and others procured useful minerals and materials found at or near the surface of the earth. Throughout Chinese history, vast amounts of building materials (such as stone, clay, lime), clays for ceramic production, and minerals such as iron, silver, copper, cinnabar, sulphur, arsenic and coal have been obtained through various forms of surface mining. One might also discuss here dredging (actually a form of placer mining) and, indeed, dredging for gold is today very important in some parts of China as I was made aware by the more than 100 dredges I saw in 1994 along the Li River 灕江 in Kwangsi between Ku-phao 古袍 and Wu-chou 梧州. I have discovered no references to dredging in pre-19th century mining, but it is possible that it may have occurred in some places using a dredge more or less similar to the one illustrated in Vol. 4, pt. 3 (p. 338).

What might be considered perhaps the simplest kind of surface mining occurred by serendipity when farmers ploughing their fields chanced to dig up pieces of native metal, or some ore that they were able to recognise and use. Later, a great deal of bog iron and coal and lesser amounts of metal ores, such as those of copper and silver, were obtained in this way (Fig. 17).[59]

[54] Cf. Vol. 5, pt. 4, p. 317. By the +11th century, the Chinese were even using for amalgamation mercury derived from a kind of purslane plant; Vol. 3, p. 679, fn. c.

[55] Sloane & Sloane (1970), p. 20. Sometimes, even a bellows could be used; *Ibid.*

[56] Torgasheff (1930), p. 125. [57] Young (1970), p. 109.

[58] For a very useful attempt to provide a systematic overview of various kinds of surface mining and related activities, see Cranstone (1994).

[59] It has been suggested that there is an etymological relationship between this primitive kind of surface mining and the character *chu* 鑄 'to smelt'; Needham (1980), p. 514. Cf. Karlgren (1964), pp. 280–1; Hua Chueh-ming (*1987*), p. 66.

Even where surface operations developed into excavations of some depth, they usually tended to remain small-scale,[60] for a number of reasons. To begin with, there was the problem of removing large quantities of overburden with the tools available to the miners.[61] Water was another obstacle. In any area where there was significant rainfall, especially in an extended rainy season, considerable rainwater would accumulate in large pits, requiring major drainage efforts before mining could begin again. This problem would not arise in the case of adits and could be easily minimised at shaft workings by the simple expedient of covering the openings during rainy periods. Many shafts in any case had permanent protecting structures over the shaft opening (Fig. 1 and Fig. 87) or were even located inside the miners' dwellings.[62]

Given the small scale of the workings, it is only to be expected that weathering over the centuries as well as human modifications of the landscape have largely obliterated their traces. Moreover, the usually simple techniques employed were not likely to draw much attention from the small number of earlier Chinese writers who showed any interest in mining techniques or, more recently, from archaeologists working on mining remains. Surface workings have rarely been the subject of archaeological excavation reports.[63] The result is that the history of this area of Chinese mining has barely begun to be explored.[64]

The small scale of most Chinese surface mining by no means meant insignificant production totals. Because such mining was so extensively practised throughout China, the product of small-scale surface mining, in terms of total tonnage, overwhelmingly dominated traditional Chinese mining (see Table 2).[65] The major products obtained by means of vast numbers of small, shallow surface operations were building materials, decorative rock such as marble, clays for ceramic production, coal and iron.[66] Particularly in the case of iron, deep-mining was seldom necessary to obtain the amount of ore required for typically small-scale premodern production levels, say a few hundred tonnes of pig iron per year.[67] Even larger operations could often be supported by surface mining: Tegengren has estimated that open-pit works averaging only 4 m in depth produced at Li Kuo-i 利國驛, the great Northern Sung iron-production centre located in the northeast corner of Kiangsu, some

[60] This was certainly true for the early 20th century; Torgasheff (1930), p. 531.

[61] By contrast, the powerful earth-moving equipment used in modern mining often makes open-pit mining less expensive than underground mining; Larson (1984), p. 8.

[62] Where shafts went down to the water level (which would rise during the rainy season), accumulated water could become a serious problem. In Shantung coal shafts at the turn of this century, it took two months of drainage efforts after the rainy season before mining could begin again; Anon. (1898–1899), p. 642.

[63] Cf. above, Section (*c*)(1). [64] See, e.g., Hsia Hsiang-jung *et al.* (*1980*), p. 357.

[65] Even as late as the Ming and Chhing, the frequent use of *khuang-chhang* 礦場 'mining field/ground/place' instead of *tung* 硐 'adit/underground passage' or *ching* 井 'shaft' to refer to silver and copper mines probably reflect the fact that most of these mines were shallow workings; Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 1, p. 239, n. 429.

[66] In Kweichow, cinnabar was often turned up just in the ploughing of fields; von Richthofen (1872b), p. 81. In Anhwei, especially where rich ores outcropped or were covered by only a shallow layer of earth, copper mining was carried on even down to the Thang and Sung periods (+7th to +13th centuries) in pits typically 20–30 m in diameter and 10–15 m in depth; Yang Li-hsin (*1988*), p. 182.

[67] Wagner (1993), p. 258.

Fig. 41. A miner in the Thao-hua 桃花 area south of Kuei-lin, Kwangsi collecting soil from which he will later wash the disseminated native gold. Original photo, 1994.

500,000 tonnes of iron ore in traditional times.[68] At the Ko-chiu 箇舊 tin mines just before World War II, the largest pits had a vertical depth of over 200 m (1,000+ *pu* 步); ore haulers might have to walk well over three km to exit the pit.[69] Surface workings on that scale required miners with special expertise that was recognised to be different from the expertise of underground specialists.[70]

In many cases, where native metals or ores were disseminated in the earth, mining consisted of the simple process of collecting earth and washing it to obtain its minerals. One can still see such activity, on a very small scale, at places like Ko-chiu where peasant miners collect disseminated cassiterite (Fig. 98) or in the Thao-hua 桃花 area in the gold belt south of Kuei-lin 桂林 where, besides underground mining of veins, there is a small amount of surface mining of disseminated native gold (Fig. 41).

Such operations could often continue for long periods of time essentially unchanged. In the right conditions, however, surface mining could lead to more complex operations. This was especially true where outcrops of either metals or coal were worked. In recent years, archaeologists have begun to provide information not

[68] Tegengren (1924), pp. 237–8. The ultimate depth of the pits was, according to Tegengren, apparently determined by the level of the ground water.

[69] Su Ju-chiang (*1942*), p. 66. At Ko-chiu, 5 *pu* was about equivalent to 1 m; Draper (1931), p. 178.

[70] *Ibid.*, p. 25.

only on larger surface excavations but also of how they could develop into underground mines.

The most extensive remains of very early surface mining, in this case of copper, are those found at Ta Ching 大井 in Lin-hsi 林西 hsien, Inner Mongolia with its more than 100 trenches over an area of 2 sq. km. These workings date to the early Chou period, –9th to –7th centuries, and are a particularly good example of the working of an outcrop to the point where the workings verged on underground mining. One trench that reached a length of about 500 m and a depth of 10 m is reported to have been only 0.6 m wide.[71] The largest single early open-pit working, dating to about the middle of the –1st millennium, was found in 1957 at Nu-la-sai 奴拉賽 in Ni-lo-kho 尼勒克 county in Sinkiang. No excavation report seems to have yet been published on mining at this site,[72] but we know that two open-pit workings were found, the largest of which was 100 m long and reached a depth of 50 m.[73] Interesting remains have also been found at what is presently China's earliest underground mine, at Thung-ling 銅嶺 in Jui-chhang 瑞昌, Kiangsi.[74] Here, a mine identified by the excavators as 'number 11' and dating back to the mid-Shang or about the –13th or –14th century shows not only a surface working but also how it developed into an underground working. The miners began with a trench excavation that, because of the weathered and broken character of the rock, required on each side a retaining wall of wooden stakes to hold back the earth and rock. At the end of this trench, (because they had gone as deep as they were able with trenching?) they sank a vertical shaft, from the bottom of which they then extended a working gallery.[75] Open pit mining was also pratised at Thung-lü shan 銅綠山, commonly to depths of 20–30 m,[76] and we have a carefully drawn view of one of the workings where the excavated pit is flanked by two mounds of gangue (Fig. 42).

A final method of surface mining, much used by the Romans in Spain, Wales, Bosnia and Hungary,[77] was hydraulicking or hushing whereby a strong current of water is used either to remove waste overburden or to break down softer beds of ore or earth impregnated with native metals. Though this practice is reminiscent of beneficiation or concentration methods used at the tin mines of Ko-chiu (see Section (*i*)(2) below), it seems seldom if ever to have been used to any significant

[71] Chou Wei-chien *et al.*, (*1990*), p. 18; Liu Shizong *et al.* (1993), p. 58.

[72] Li Yen-hsiang & Han Ju-pin (*1990*) deals exclusively with the smelting technology employed here. See now, however, Mei Chien-chün & Li Yen-hsiang (*1995*).

[73] Chou Wei-chien *et al.* (*1990*), p. 19; Liu Shizong *et al.* (1993), p. 61; Lu Pen-shan & Liu Shih-chung (*1993*), p. 34.

[74] See above, Section (*e*)(1)(i)(8).

[75] Chou Wei-chien *et al.* (*1990*), pp. 19–20. Excavators at the Chin-niu tung 金牛洞 mine in Thung-ling 銅嶺, Anhwei hypothesise that mining began there in essentially the same way after open pits had reached a depth of some 8 m; Yang Li-hsin *et al.*, (*1989*), p. 917.

[76] Yang Yung-kuang *et al.* (*1980–1981*), p. 88; Barnard (1989), pp. 170–1.

[77] Forbes (1963), p. 203. Davies (1935), pp. 18, 100ff., 110, 204. Some questions have been raised about whether the evidence of hushing at Dolaucothi in Wales actually dates from the Roman period; Cranstone (1994), p. 145.

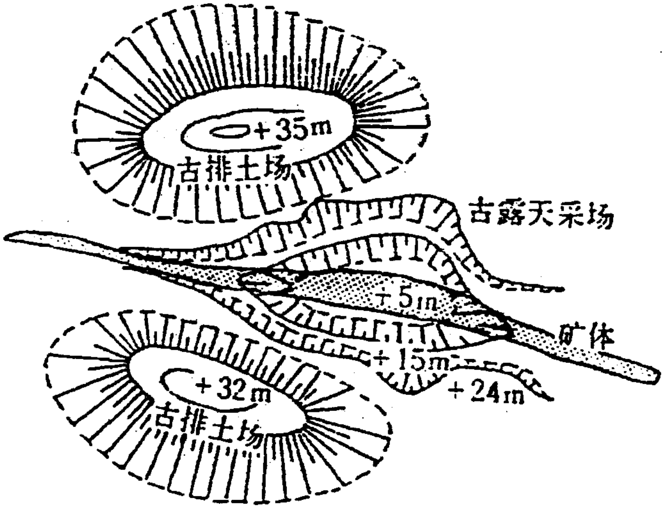


Fig. 42. An ancient open-pit working (*ku lu-thien tshai-chhang* 古露天采場) at Thung-lü shan 銅綠山. The work started from 24 m above sea level and proceeded into the ore body (*khuang thi* 礦體) to a depth of 19 m (5 m above sea level). On either side are ancient mounds of excavated waste (*ku phai thu chhang* 古排土場) rising to heights of 35 and 32 m above sea level. Yang Yung-kuang *et al.* (*1980–1981*), p. 88.

extent for mining in China.[78] The reason may well have been that this pre-eminently labour-saving technology, requiring heavy capital investment up front, hardly recommended itself in the context of Chinese mining where labour was cheap but capital was at a premium (see Section (*k*)(5) below).[79]

[78] H. Louis does describe Chinese gold miners in Malaysia using hushing together with heavy iron-tipped crowbars to remove earth and surface rock from quartz reefs: 'A small water furrow is first brought in at the highest possible level on a suitable hillside. The principal tool used by these Chinese miners is a heavy long wooden crow-bar, shod with a long strongly made chisel-pointed iron socket. With the help of this and of the stream of water, which rarely exceeds 50 cu. ft. per minute, the surface soil and weathered country rock are loosened and sluiced away. No trouble is taken to save any of the gold washed down, except in one or two instances where rude riffles have been inserted in the tail race; the sluice is, however, carefully searched for bits of quartz showing visible gold, which are picked out and put on one side. The surface of the shales is thus stripped, and any veins of gold that may be laid bare are then worked . . .'; Louis (1891), p. 640.

[79] Rodman Paul (1963, p. 30) also points out that one seldom encountered the combination of natural conditions (extensive shallow deposits, abundance of water, and hilly terrain capable of giving the water a sufficient 'fall') that made use of this process feasible.

(*h*) UNDERGROUND MINING

Tis his to find the glittering ore
For ages hid in earth's dark womb,
To creep and climb, to dig and bore
And build himself a living tomb
Some six feet high, some four feet wide
And reached o'er depths that few would stride.

'The Owyhee Avalanche', Boise, Idaho[1]

(1) Beginnings of Mining Underground

The same grubbing for surface rocks that evolved into placer mining (cf. Section (*g*) above) undoubtedly also led in some cases by imperceptible steps to the first true underground mining.[2] No great imaginative leap was necessary for proto-miners who were already digging out rocks partially embedded in the earth to come up with the idea that useful materials might be found completely covered over and perhaps even at some depth.[3] In some areas, such as western Europe and England, the search for high grade flint required mining at some depth[4] but we have as yet no evidence that flint played any significant rôle in early Chinese mining. On the other hand, once the usefulness of metals had been discovered, the search for pieces of native copper certainly encouraged digging underground.[5]

An alternate route to true underground mining, as we have seen ((*g*)(2)), was the progressive working of relatively well-defined outcrops that led miners bit by bit to push deeper into the earth, a process that might well develop into the digging of shafts (Fig. 62). In all of this, we should not ignore the likely rôle of potters. As Cheng Te-khun reminds us, 'the Neolithic potter was a keen explorer of natural resources'. Different clays result in very different kinds of fired bodies and the early potters carefully selected those clays that were best for their purposes. Moreover, iron, copper, manganese and other ores were a source of pigments for decorating pots.[6] Even for repairing broken vessels, a paste prepared from lime concretions was used.

[1] A Boise newspaper, cited in Todd (1967), p. 69. [2] Barnard (1989), p. 148.

[3] As happened in other areas also, such as North America: '. . . in North America quite a number of "mines" are known, where large pebbles and boulders were dug out of lightly consolidated ancient gravels by digging pits, and even small chambers, into the deposit. The tools were frequently roughed out on the spot.' Rosenfield (1965), p. 195.

[4] Shepherd (1980), p. 112.

[5] Hsia Hsiang-jung *et al.* (*1980*), p. 6. It could well be that Europe had more flint available in workable horizons (Shepherd (1980), p. 167) than did China, while the opposite was true for copper and copper ores.

[6] Cheng Te-khun (1974), pp. 222–3. The red/brown colours on the famous Yang-shao 仰韶 pots, for example, were produced by pigments made mainly from hematite; the black pigments were derived mainly from iron or manganese ores; Hsia Hsiang-jung *et al.* (*1980*), p. 12.

In any case, Chinese miners by the late Neolithic period were not only exploiting outcrops by means of open-pit workings but had already moved on to true underground mining.[7]

(2) Minimising Excavation

The ideal underground ore deposit for traditional miners was enclosed in country rock that was soft enough to be worked without too much difficulty but was compact and strong enough so as not to be prone to collapse. There were, unfortunately, few ideal deposits. In the early stages of mining, before timbering techniques had been developed, a strong country rock not susceptible to caving was especially important for the safety of any excavations at depth. But without power tools, breaking through such rock was an arduous and extremely slow process. If the rock was relatively soft, traditional miners could perhaps advance at the rate of 15 cm every 24 hours. Progress through hard rock might not exceed 10 m a year.[8]

It is not surprising, then, that Chinese miners avoided unnecessary breaking of rock whenever they could.[9] The result was a kind of mining in which the miners carefully followed wherever the veins led, while doing everything possible to avoid excavating surrounding country rock or poor tenor ore.[10] An interesting example is seen in the Warring States copper mine at Ma-yang 麻陽 in Hunan. Here, by carefully selecting good ore for excavation while leaving in place poorer quality ore, the miners produced two-level drifts or galleries where the foot of the upper level and the roof of the lower level were formed by a layer of poor quality ore (Fig. 43). At least by Ming times, the Chinese themselves referred to mines that closely followed the windings of the ore as 'worm eaten wood' (*chhung tu mu* 蟲蠹木)[11] or mouse holes (*shu-hsueh* 鼠穴).[12] Later foreign observers typically disparaged it as 'rabbit warren' mining or 'burrowing' or 'gophering' (Fig. 44).[13] Those who had a better understanding of the context of Chinese mining were slower to deride the practice. Japanese observers in the 19th century, for example, were impressed by the ability of the Chinese miners to work in extremely cramped drifts, recognising how this minimised excavation labour.[14] There were also other constraints over which the miners had no control and that sometimes forced them to follow far from optimal

[7] Lu Pen-shan (*1990*), n.p. Though we as yet have no direct evidence of underground mining in Neolithic China, the excavation capabilities of the Chinese at this time are well attested by storage pits, wells, tombs, moats and reservoirs; Barnard (1989), pp. 148–50.

[8] Neuberger (1930), p. 4; Hollister-Short (1985), p. 56.

[9] Slessor (1927), pp. 60–1. They were hardly alone here. As Paul Craddock puts it so well: '[E]arly miners everywhere were very reluctant to dig anything that was not ore.' Craddock (1987), p. 183.

[10] Coal seams were often worked only where they were thick enough so that the miners did not have to cut into the walls; Pumpelly (1866), p. 20.

[11] *Shu Yuan Tsa Chi*, ch. 14, 9a; Hsia Hsiang-jung *et al.* (*1980*), p. 295.

[12] Yang Li-hsin (*1988*), p. 187.

[13] For a fine illustration of the same kind of mining at the great Kutna Hora silver mines in Bohemia in late medieval Europe, see Gimpel (1977), p. 71.

[14] Davidson (1903), p. 465.

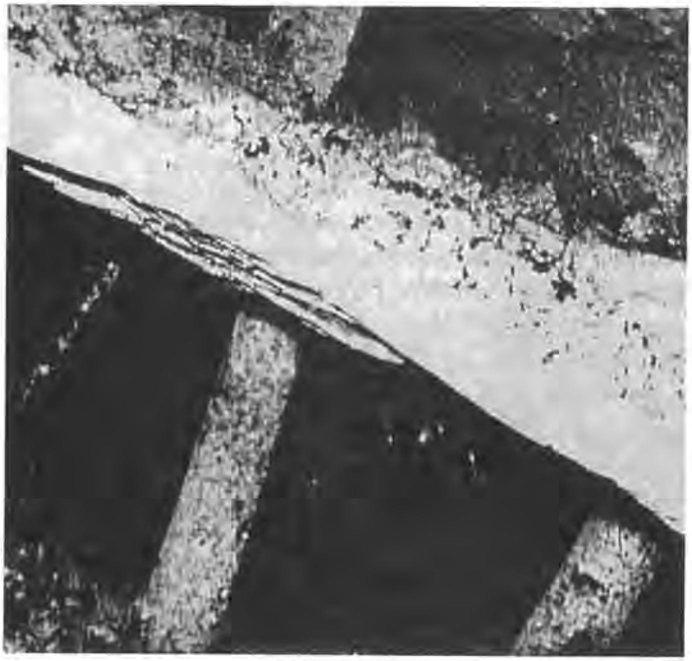


Fig. 43. A two-level inclined shaft from the Warring States copper mine at Ma-yang 麻陽 in Hunan. The layer of ore (white in the photograph) forming the foot of the upper level and the roof of the lower level consists of a greyish white feldspathic quartz sandstone 0.4 m in thickness and containing only about 0.2% copper. Hsiung Chhuan-hsin *et al.* (*1985*), p. 119 and pl. 2, no. 5.

mining practices. The owners of mining tracts in China, just as their counterparts in modern Bolivia, had potentially much to gain by granting prospecting and mining rights to a maximum number of miners and thereby increasing chances of a strike.[15] This, too, encouraged labyrinthine workings marked by a maximum of small excavations heading in all directions according to the vagaries of the ore or the skill or luck of the miners.[16]

(i) *Excavation tools*

It seems to be a characteristic of premodern mining anywhere that most of the tools that come to be used widely in a mining tradition make their appearance relatively early. From then on, their forms persist largely unchanged, except for perhaps becoming larger and heavier. In Europe, the tools used by the +16th century miners commonly differed little, if at all, from what had been available to their counterparts

[15] Godoy (1985), p. 153.

[16] An important result of this kind of working was that it often left the mines unsuitable for exploitation at a later time; Furth (1970), p. 60.

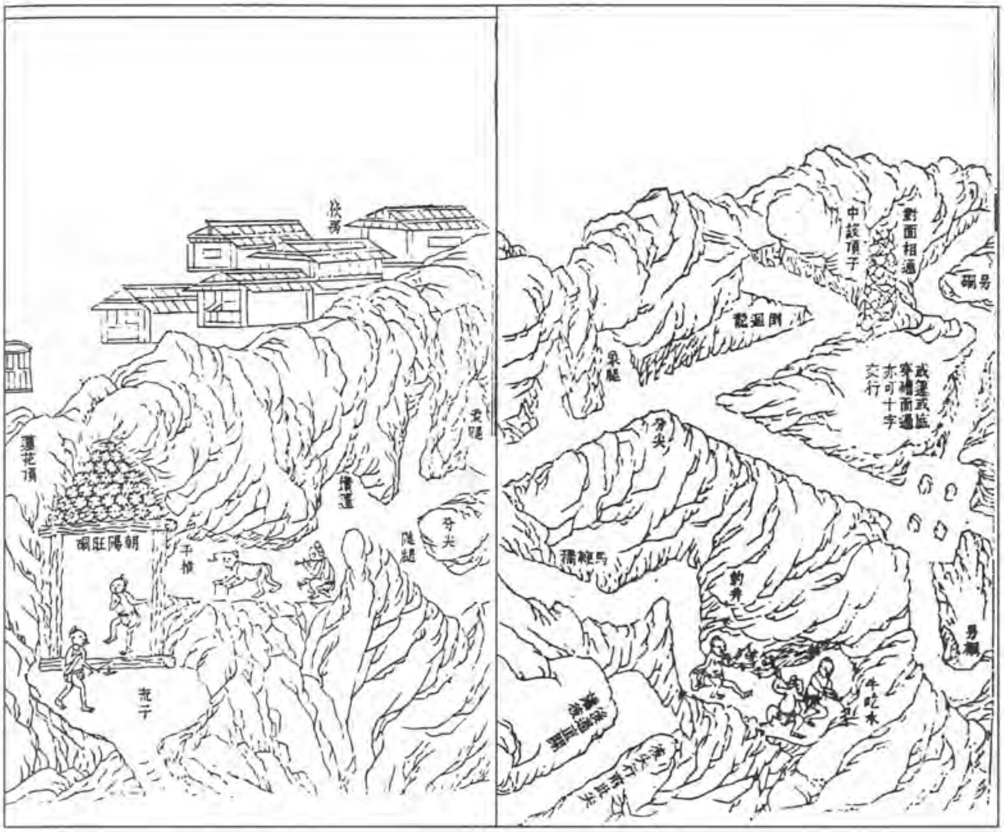


Fig. 44. A large 19th century underground copper mine in Yunnan. At the lower right, a two-man team is excavating ore with one man holding a gad or chisel and a second wielding a heavy hammer that weighed from three to five *chin* or about one-and-a-half to three kilograms; Wu Chhi-chün (*1845*), ch. 1, p. 4a. The third man, sitting and resting, will haul the ore away. The lamp he is holding, after being stuck into his head cloth, will light his way as he crawls to the surface; see the crawling miner on the left side just about to reach the opening of the mine. That miner is using two 'crawling sticks' well described by Draper (1931, p. 184) as 'a T-shaped stick 12 in. long by 6 in. high (?) which, grasped at the middle, serves as a sort of hand crutch to keep one hand off the rough slimy floor of the incline, and as a support for the back sack when the coolie stops to rest'. The artist tries with limited success to illustrate various kinds of shafts and galleries. In the background on the left are the living quarters for the workers.

in classical antiquity.[17] In China, even the miners at large-scale operations, such as the copper mines of Yunnan in the +18th century, still relied overwhelmingly on mallets and chisels, mattocks and hoes in form much like those of their forerunners who attacked the copper ores of Thung-lü shan 銅綠山 in the Spring and Autumn period.[18]

[17] Bromehead (1956), p. 8; Smith (1967), p. 143. Some scholars would go even further. Shepherd (1980, p. 182) argues that the 'tools and other equipment used by the miners [in the prehistoric copper mines of Austria] were the ancestors of tools used in the industry up to a decade ago.'

[18] Wu Chhi-chün (*1845*) (several examples in illustrations); Sun (1964), p. 63. The mallet/chisel combination was so much the norm that the miners frequently referred to the left side as the 'mallet side' because the miner wielding the mallet worked on that side, while the right side was the 'chisel side'.

Like other workers and craftsmen, miners in China worked with a small number of simple but effective and flexible tools.[19] Despite the widely varied types and conditions of mining, the tools used show little change over time either in shape or, after the introduction of iron, in material of which they were made. This also holds true surprisingly often across different kinds of mining.[20]

In early times, as the materials used for making mining tools advanced from stone, wood and bone to bronze or copper and iron, evolution of better tools making full use of the potential of each new material was probably slowed to some extent by the phenomenon seen in all cultures of skeuomorphism or the tendency to fashion new materials into shapes more appropriate to earlier materials until the potential of the new material had come to be better understood.[21] In later times, specialisation of tools may have been impeded in some measure by the universal pride of the craftsman in his own personal skill, his 'knack'.[22]

But conservatism and cost were almost certainly the decisive considerations here. The roots and expressions of Chinese conservatism may be complex and its impact may be hard to measure, but it coloured in one way or another every reaction of the Chinese to their environment.[23] It was a powerful force for the preservation of the old, whether ways of doing or ways of thinking.[24] In Chinese mining, that conservatism consistently hindered change of any kind, including the introduction of new tools and mining methods.

The inhibiting effect of conservatism was abundantly reinforced by the hard reality that most Chinese miners, struggling just to meet their basic needs, could hardly afford any but the cheapest and therefore most primitive tools. In the case of many who engaged in mining only as a part-time supplementary activity, general purpose tools that could be used, say, in both farming and mining would be preferred to more specialised tools.

[19] One thinks of professional chefs in China who still do all of their cutting and chopping with a single cleaver. The very flexibility of the tools poses its own problems for modern archaeologists and historians who study them: while the uses of some of the tools are obvious at a glance, it can be very difficult to know how others were used; Wagner (1993), pp. 41, 209. Hence the lack of standardised terminology in the archaeological reports which makes careful study of the tools themselves (even if only in photographs and drawings) more important than reliance on the names the excavators apply to them; Wagner (1993), p. 150.

[20] This phenomenon is by no means limited to China. For example, Ricardo Godoy notes of contemporary tin mining in Bolivia: 'The mining equipment and tool kits are uniform across mines regardless of differences in mineralised reserves.' (Godoy (1985), p. 151.) What may be unique to China (this is a topic needing further study) is the extent to which similar tools prevailed despite not only the variety of the deposits of any given mineral but also the range of minerals and materials mined.

[21] See Basalla (1988), pp. 106–7 and Sayce (1963), esp. pp. 80–93, which provide many examples from ancient as well as modern cultures. For a group of examples from China, see Barnard (1961), p. 60, fig. 16 which shows a number of Shang bronze vessels and their pottery prototypes. I am grateful to Graham Hollister-Short for drawing my attention to this phenomenon, for the reference to Sayce, and for the comment, important for what follows, that 'skeuomorphism is *not* conservatism in the sense of there being any conscious volition involved'. (Personal communication)

[22] Cf. Vol. 2, pp. 121–7.

[23] In this, China was by no means alone among traditional societies; see Mokyr (1990), pp. 154–5.

[24] Modernisation efforts over the last two centuries, of course, repeatedly stumbled over this same rock of conservatism. To be sure, those persons to be 'modernised' can sometimes recognise explicitly or intuitively that the new ways of doing things will bring unwanted changes or risks to their lives. But often it was a generalised satisfaction with things as they were that mitigated against changes of any kind. For such thinking among contemporary Bolivian miners, see Godoy (1985), pp. 150–1.

Fig. 45. Earliest (?) bone pick discovered in China in connection with a mining site, in this case at Ta-ching 大井, Lin-hsi 林西 county, Liaoning. It dates from the first half of the –1st millennium (Late Western Chou – Spring and Autumn period). Barnard (1989), p. 169, fig. 9; Wu Chia-chhang (*1983*), p. 143, fig. 9, no. 6.

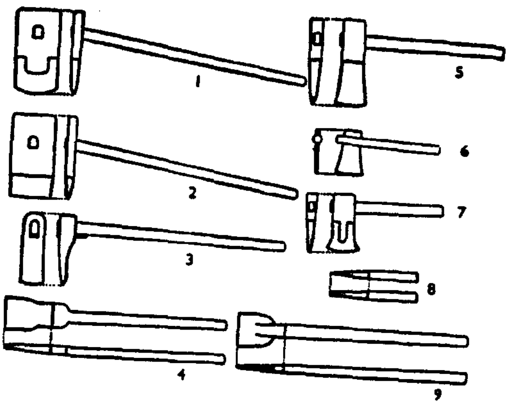


Fig. 46. Reconstructions of Warring States iron implements from Ku-wei village, Honan. Cheng Te-khun (1963), p. 247. On the difficulty of identifying early tools and the possibility that one implement might have served as more than one kind of tool, see Rostoker *et al.* (1983), p. 198, but note also Wagner's comment (1993, p. 218, fn. 11).

Finally, we noted in the introduction that one of the unique elements of mining as a technology was its heavy reliance on brute strength and endurance. Nothing could significantly change that in the traditional context, certainly not tools with marginally improved designs.[25]

Up to the mid or late Shang, Chinese miners relied chiefly on relatively small tools made of bone, wood and stone (Fig. 45). Only very gradually did they begin using larger and heavier tools,[26] and to incorporate bronze in their manufacture.[27] Among these, axes (Fig. 46), chisels or wedges (Fig. 46 and Fig. 47), and gads (Fig. 48) that have been excavated from pre-Han and Han mines were probably some tools

[25] This of course did not preclude at least small improvements in tools and even a certain amount of specialisation of tool forms; Lu Pen-shan & Liu Shih-chung (*1993*), p. 35.

[26] Lu Pen-shan (*1990*), n.p. One axe from the Spring and Autumn period excavated in Hupeh weighed an imposing 16.3 kg.

[27] Vogel (1982), p. 145.

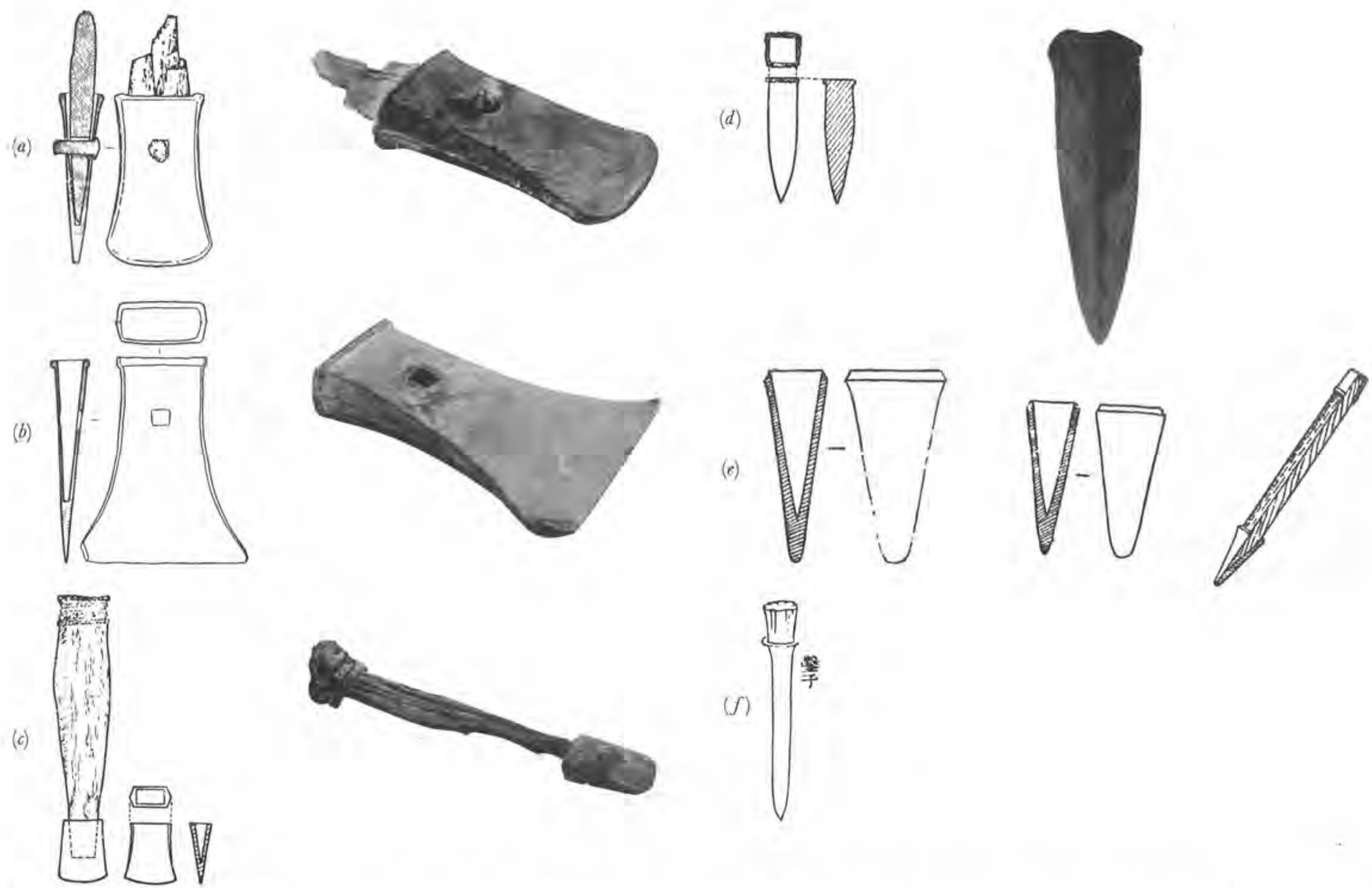


Fig. 47. Chisels (*tsao* 鑿 or *tsan* 鏨) or chisel-like mining tools. (*a*) Chisel with axe-shaped (*fu* 斧) head of bronze. Haft, 70–80 cm in length, secured by pin passing through eyehole in head. Cutting edge perpendicular to haft, weight 3.5 kg, cutting edge 22 cm. Lu Mao-tshun (*1974*), p. 252, fig. 52 and pl. 7. (*b*) Chisel or adze (Anon. (1980)) with axe-shaped head of bronze. Pin to secure haft. Cutting edge perpendicular to haft. *Ibid.* (*c*) Chisel with axe-shaped head of cast iron. Total length 47 cm. No pin to hold haft, probably because iron had less 'give' than bronze. Four bands of bamboo wrapped around the upper end of the haft, probably to inhibit splitting. Anon. (*1975*), fig. 12 and pl. 4. (*d*) Four-sided chisel of wrought iron, length 22.5 cm. *Ibid.* All the above are from Thung-lü shan 銅綠山. (*e*) Two triangular chisel heads, 7.8 and 9.8 cm, from the 'Golden Ox' (*chin-niu* 金牛) mine at Thung-ling and a reconstructed chisel, length 39 cm. Yang Li-hsin *et al.* (*1989*), p. 915 and p. 916, fig. 9. (*f*) Chisel (*tsao-tzu* 鑿子) from Yunnan, 19th century. Wu Chhi-chün (*1845*), Illustrations, p. 11a.

Fig. 48. Three bronze 'pig's tongue' (*chu-she* 豬舌) gads (*pen* 錛) from Thung-lü shan 銅綠山, length 7.0–9.2 cm. All have eyeholes for a pin to secure their handles. Lu Mao-tshun (*1974*), pl. 9. Yang Yung-kuang, Li Chhing-yuan and Chao Shou-chung speculate that these gads, widely used in the Western Chou period, were hafted in such a way that, like an axe, the cutting edge was parallel or near parallel to the handle. They provide no evidence for this reconstruction, however. Yang Yung-kuang *et al.* (*1980–1981*), pp. 88–9. It seems equally possible that they formed the head of a digging stick essentially like those still used in Chinese coal mining in the 19th century; and perhaps even today; see Fig. 22.

that were used only in mining.[28] Nevertheless, throughout the history of Chinese mining, the norm was considerable overlap of mining tools and the tools of other occupations, especially agriculture (Fig. 49).[29]

More than the design or modification of tools to meet the special needs of mining, it was the materials from which the tools were made that largely determined their effectiveness. The unique requirements in mining for the application of brute force make great demands not only on the miners themselves but also on their tools, where strength and durability are essential qualities.[30] Keeping this in mind, it is not difficult to appreciate why wooden and stone tools remained dominant in Chinese mining right into the Warring States period.[31] Once shaped, tools made of hard stone would possess considerable durability. Even wood, where it was available in hard and strong varieties or where it could be treated to increase its hardness, was a

[28] Interestingly, no implements that can be unequivocally identified as picks or pick-axes seem yet to have been discovered in pre-Han mines. They were, however, already a part of the Chinese toolkit; see Wagner (1993), p. 37, Fig. 1.8 for two examples.

[29] One tool typically found in a miner's version is the straight pick, apparently a modification of the curved pick, which in most if not all cases probably derived from the use of the horns of animals for prying actions. Cf. below and Raistrick (1972), p. 24.

[30] It is easy to miss the toll that mining takes on tools. Bromehead has provided one of any number of possible examples, noting that 'in the salt mines at Hallstatt a modern miner uses ten steel picks in an eight-hour shift'; Bromehead (1942), p. 196.

[31] Vogel (1982), p. 145. And they continued to be used in mining or other occupations right down to this century. Hommel in the 1920s found stone hammers still in use to drive wedges in a 'primitive oil press'; Hommel (1937), p. 2. In parts of Europe, flint and wooden tools continued to be used in mining until the Middle Ages; Forbes (1963), p. 192.

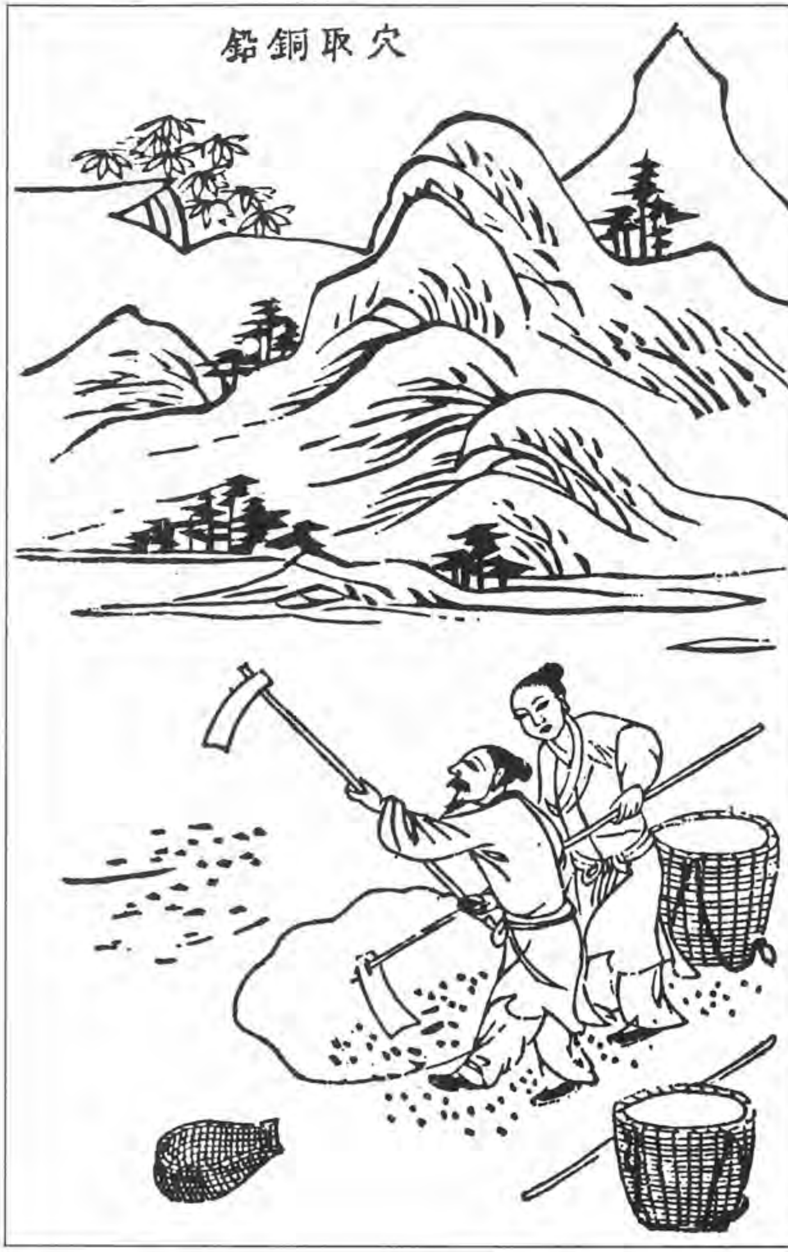


Fig. 49. Peasant(?)-miners using the same kind of mattocks as used in farming to dig for copper and lead ores. Sun & Sun (1966), p. 243. The curiously shaped basket in the lower left, seen in Fig. 60 and perhaps also in Fig. 82 and in Wagner (1985), p. 7, fig. 2 and p. 9, fig. 3, served as a kind of basket/shovel and seems to have been widely used especially in coal mining; Anon. (1910), p. 761.

(a) (b)

Fig. 50. Iron scrapers (gouges(?), rakes(?)) identified as *pa* 耙 from Thung-lü shan 銅綠山. (*a*) 50 cm long, with 12 cm wide blade. Lu Mao-tshun (*1974*), pl. 9. See Anon. (1980) for colour plate. (*b*) Cast iron scraper, 50 cm long with 9.3 cm wide blade. Anon. (*1975*), fig. 12 and pl. 4.

very serviceable material for mallet heads, crowbars, etc., as well as being an obvious choice for handles of all kinds.[32] Of course, wood ordinarily also had the advantage of being easier to shape than stone.

It is hardly surprising then that metal came only very slowly to be used for mining tools. The first candidate, copper, was in reality not an option, being too soft for most purposes. Much of early bronze would be only marginally better, though here the main impediment was undoubtedly cost, which not only limited the number but also the size of the bronze tools used.[33] For example, bronze tools excavated at Thung-lü shan 銅綠山, expecially those said to date from the first half of the –1st millennium (Western Chou and Spring and Autumn periods), tended to be small in comparison with tools from the following centuries.[34] This helps account for the extreme narrowness of the shafts and galleries in this period. These small bronze tools were limited not only in their ability to break rock but also in their efficiency in cutting and shaping timbers for supports, thus further encouraging openings as small as possible.

The picture changed dramatically, however, with the availability of both cast and wrought iron in the Warring States period. Now metal began to replace wood and stone extensively in certain tools. This occurred not only with the tools mentioned above but also with others such as scrapers (or rakes or gouges) and hoes (Fig. 50).

[32] Hsiung Chhuan-hsin *et al.* (*1985*), pp. 119–20. The strength of wooden implements was frequently maximised by carving them out of single pieces of wood. Stresses on such implements were much more evenly distributed across their entire surface than would be the case for implements assembled from two or more pieces; Chou Pao-chhüan (*1984*), p. 72.

[33] Bronze, however, *was* used to some extent for ordinary tools throughout China and neighbouring areas, though perhaps not extensively for agricultural tools except in the lower Yangtze region; Wagner (1993), pp. 33–41; Vogel (1982), p. 45. Interestingly, miners at the other end of the Eurasian continent seem to have largely skipped the stage of bronze tools, or at least picks. The earliest metal picks in Western mining were made of iron; Forbes (1963), p. 192.

[34] Chou Pao-chhüan (*1984*), p. 71.

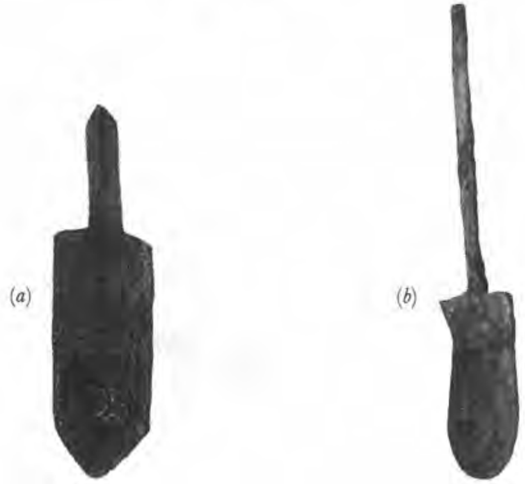


Fig. 51. (*a*) Wooden shovel (*chhan* 鏟) from Thung-lü shan 銅綠山, blade height 30–40 cm, width 10 cm. Lu Mao-tshun (*1974*), pl. 8 and p. 253. (*b*) Wooden spade (*chhiao* 鍬) from Thung-lü shan, total length 76 cm. *Ibid.*

Fig. 52. Wooden scoop (*phiao* 瓢) from Thung-lü shan 銅綠山. Anon. (*1975*), fig. 14, pl. 5.

Advances in iron technology continued to provide improved tools for miners throughout the Warring States period and into the Han. Tools that had to be able to withstand shock came to be made of steel or malleable cast iron, which were produced in China at least by the –3rd century.[35] The easy availability of good iron and steel for tools may well have had an even greater effect on mining than on agriculture.

Of course, for uses where strength and durability were less of a concern, wood remained the material of choice for economic as well as other reasons. Thus we find at Thung-lü shan 銅綠山 wooden shovels and spades (Fig. 51), scoops (Fig. 52) and buckets (Fig. 53 and Fig. 54), and wooden implements outnumber all others.[36] Moreover, as Donald Wagner has astutely pointed out, the 'mechanical properties

[35] See above, Section (*e*)(2).

[36] Vogel (1982), p. 145. Of course, one should not read too much into this fact. We are talking about only one site, even if a very important one. More to the point, the cheaper and relatively less durable wooden implements would presumably be left behind much more frequently than metal tools and implements. Cf. also above, Section (*g*) for wooden washing pans and Yang Li-hsin *et al.* (*1989*), p. 916 for a wooden wedge.

Fig. 53. Wooden buckets (*thung* 桶) from Thung-lü shan 銅綠山. Anon. (*1975*), figs. 9–10, pl. 5.

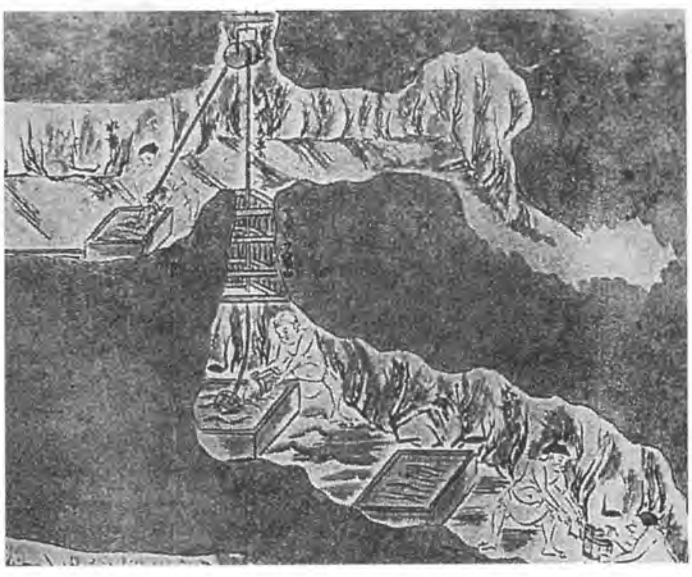


Fig. 54. A 'water ladder' bailing operation in a gold mine on the Japanese island of Sado in the +17th century. No picture of a similar Chinese operation has come to my attention but the depiction in this scroll seems to capture equally well how it was done in Chinese mines. Illustration in colour in Wilsdorf (1987), pl. 86. (See also Fig. 83.)

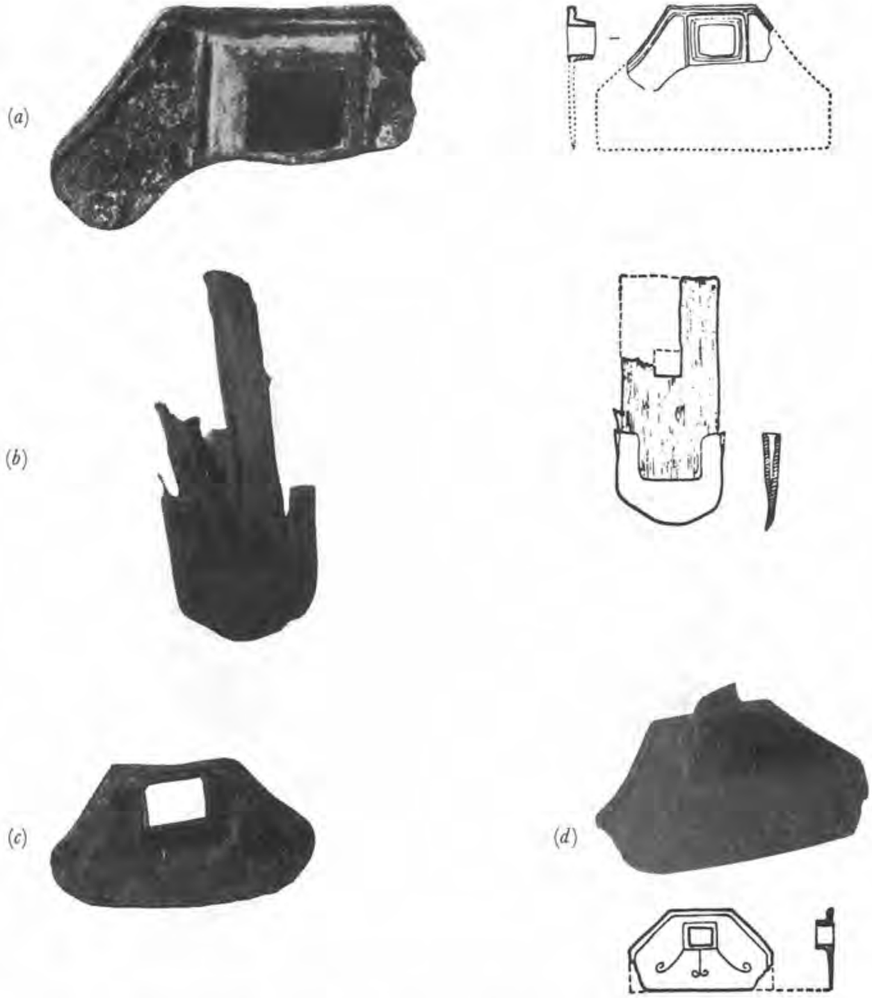


Fig. 55. Hoes (*chhu* 鉏) used at Thung-lü shan 銅綠山. (*a*) Piece of a bronze hoe blade, estimated to have been the same size as (*c*). Lu Mao-tshun (*1974*), fig. 2 and pl. 7. (*b*) Indented cast iron hoe blade. Anon. (*1975*), fig. 12, pl. 4. (*c*) Cast iron hoe blade, 15.6 cm at widest point. Lu Mao-tshun (*1974*), pl. 8. (*d*) Cast iron hoe blade, 17.5 cm at widest point. Anon. (*1975*), fig. 12, pl. 4.

[of wood] neatly complement those of cast iron. It has high tensile strength where cast iron has high compressive strength; it is springy where cast iron is hard and inflexible; and it is relatively light where iron is heavy.'[37] Thus, for many tools, a basic wood construction with only a rather small cutting or scraping edge of iron was a very practical combination. In mines, tools incorporating the two materials included hoes, shovels and spades, adzes, and axes (Fig. 55).[38] Of course, where

[37] Wagner, unpublished manuscript. Cf. also Gordon (1976), pp. 129–53. For a particularly striking blend of the characteristics of the two materials, see the quarryman's sledgehammer pictured in Hommel (1937), p. 13.

[38] Cf. also the many illustrations in Wagner (1993).

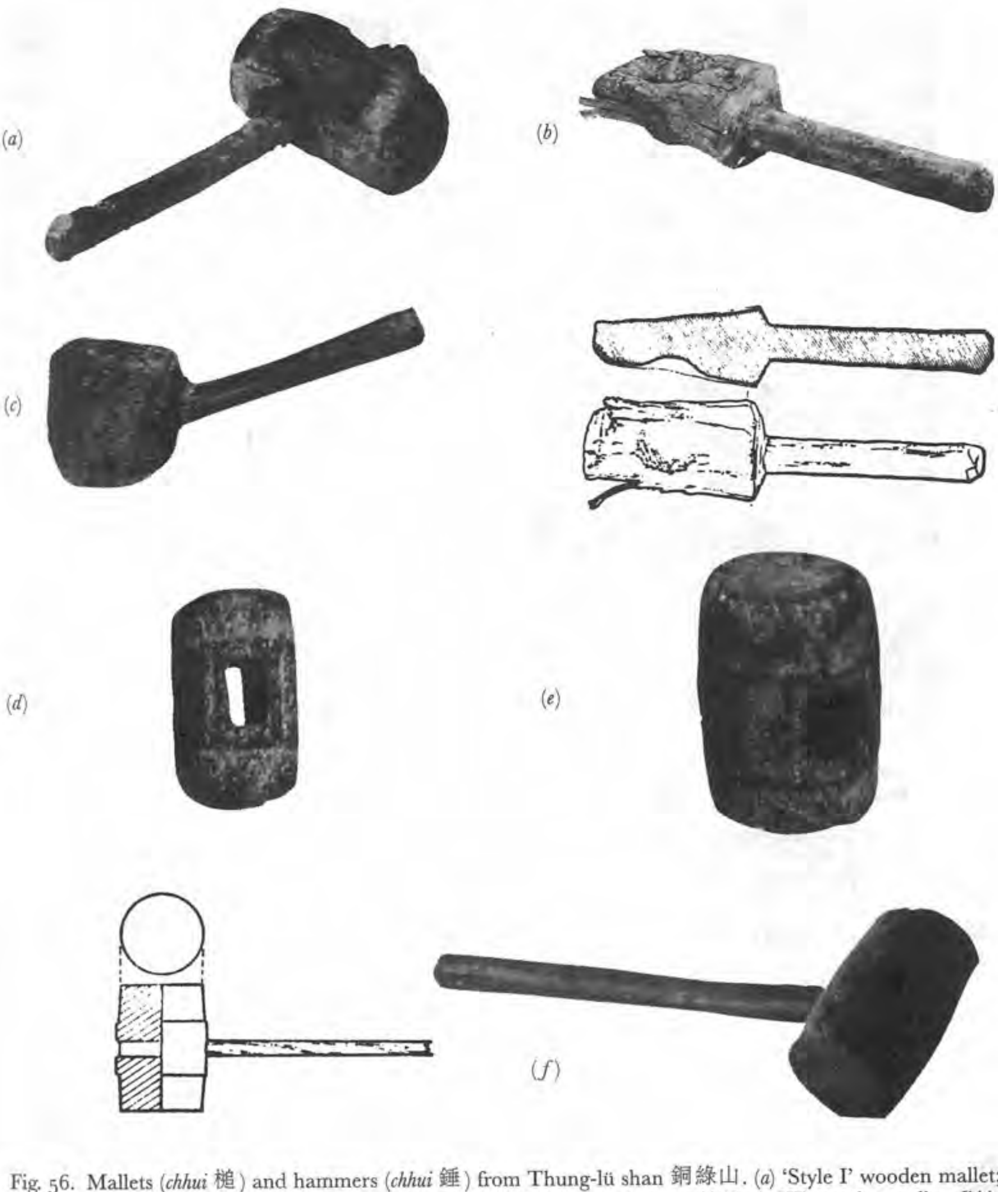
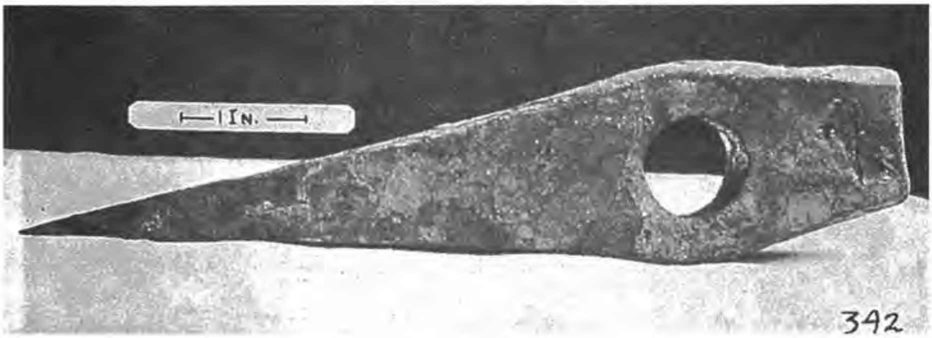


Fig. 56. Mallets (*chhui* 槌) and hammers (*chhui* 錘) from Thung-lü shan 銅綠山. (*a*) 'Style I' wooden mallet; Lu Mao-tshun (*1974*), pl. 8. (*b*) 'Style II' wooden mallet. *Ibid.*, pl. 7 and p. 252. (*c*) 'Style III' wooden mallet. *Ibid.*, pl. 8. (*d*) and (*e*) Poorly cast iron hammer heads. *Ibid.*, pl. 9 and p. 253. (*f*) Two-handed hammer with 6 kg cast iron hammer head. Anon. (*1975*), p. 7, fig. 12 and pl. 4.

weight was desirable, as with mallets or hammers (Fig. 56), iron heads would be much preferred over wood.

Often, the kind of hammers, chisels and other tools used was dictated by the size of the working area. Thus, Kiangsi coal miners in the 1920s had one set of tools for working in relatively cramped areas (Fig. 57 and Fig. 58) and another set for more

(a)



(b)

(c)

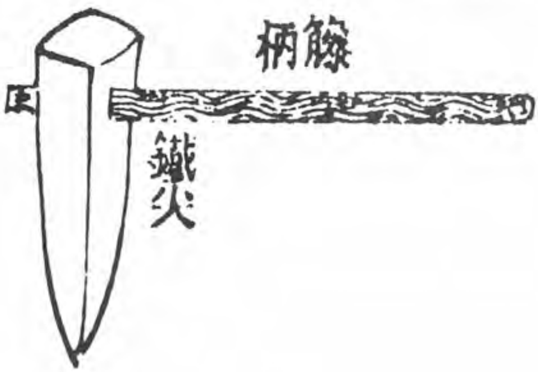


Fig. 57. Kiangsi coalminer's hand-gad or excavating chisel (*a*) and a discoidal hammer (*b*). These tools would be usable in close quarters, where both would be manipulated by a single miner, the gad held in the left hand and the hammer wielded by the right. The hammer consists of a 10 cm thick iron disk mounted on a wooden handle. Hommel calls it a 'curious hammer' though the head shape can be explained at least partly by the desire to make the small hammer as heavy as possible to maximise the force of its impact in a confined working area. The round shape would also provide a maximum of striking surfaces, all with the same 'feel'. Hommel does not explain the hole in the chisel, though he explicitly says this wedge does not have a handle. Hommel (1937), pp. 5, 8–9, figs. 14 and 15. In 19th century Yunnan, metal miners used a hammer that seems to be very similar to the Kiangsi coalminer's hammer. The head of the hammer is described as 'round and somewhat flattened' (*hsing yuan erh shao pien* 形圓而稍扁). It could weigh anywhere from three to five *chin* (1½–3 kg). Wu Chhi-chün (*1845*), ch. 1, p. 4a. Similarly, Yunnan miners also used what seems to be the same kind of gad (*c*), called here an 'iron point' (*thieh-chien* 鐵尖). In this case, the gad is provided with a cane handle (*theng-ping* 籐柄). Wu Chhi-chün (*1845*), Illustrations, p. 11a.) For an example from an unidentified coal mine, see Fig. 58.

Fig. 58. Coal miner using a mallet with a rounded stone head and an iron gad with a cane handle to break rock in order to get at coal. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 115, pl. 8. (Compare Fig. 22 and Fig. 62.)

spacious workings (Fig. 59). For softer matrixes and ores, Chinese miners typically resorted to the mattock, identical with the tool ubiquitous in Chinese agriculture (Fig. 49, Fig. 60 and Fig. 98). The popularity of this tool must have been in large part due to its flexibility: it could serve both as a pick and as a hoe.[39] Indeed, mattocks can be viewed as occupying one end of a continuum of tools in which the cutting

[39] Thus, Wong Lin-ken writes about the Chinese tin miners in Malaya: 'In the field of mining equipment, the Chinese have been credited with the introduction of the *changkol*, a versatile kind of hoe, which could be used as a pickax, a shovel, and an instrument to stir the mixture of ore and water in a sluice box.' Wong Lin Ken (1965),

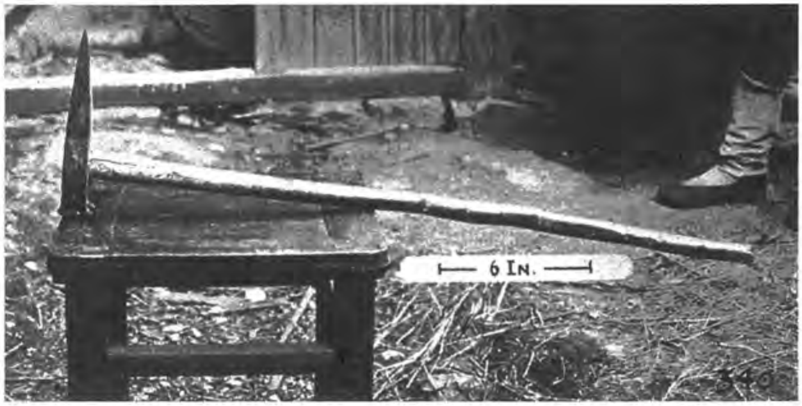


Fig. 59. Kiangsi coalminer's handled wedge or gad and long-handled gad hammer. Used in larger working areas by two miners, one to hold the point of the gad against the coal seam, the other to drive the point in by striking the flat face of the gad with the hammer. Hommel (1937), pp. 7–8, figs. 12 and 13.

blade increasingly narrows (Fig. 46, Nos. 1–3) until one arrives at a true pick where at least one (and in Chinese mines usually only one) end comes to a point (Fig. 61). Here again, the use of the tool must often have been inhibited by a lack of working space. One answer was very short-handled picks that did not require a great deal of space to use (but which were correspondingly limited in their effectiveness).[40] Another solution was the short, single-point pick where the opposite, flattened end could be struck by a hammer, thus converting the pick effectively into a handled gad (Fig. 57, Fig. 59 and Fig. 61).[41]

p. 48. Wong must be referring here to something very close to a mattock, though it is hard to see how this tool could have served well as a shovel. Unfortunately, the one picture he provides of *changkols* is insufficiently distinct to show just what shape they had or how they were constructed. It is probably these tools that H. Louis refers to as 'broad hoes', also noting that they take the place of shovels; Louis (1891), p. 640.

[40] Tegengren notes that the 'picks' used by Shansi iron miners were only about 0.15 m long but does not make clear whether he is referring to head or handle length; Tegengren (1924), p. 164. Hommel notes that coal miners he was familiar with were similarly prevented from using even their approximately 75 cm sledgehammers underground for lack of space; Hommel (1937), pp. 5 and 6, fig. 10. (I have estimated the length of the sledgehammer according to the scale of the picture.)

[41] Chinese miners do not seem to have used tongs or pincers to hold gads as was the common practice, for example, at the Japanese gold mine on Sado Island in the +17th century; Bromehead (1942), p. 195.

Fig. 60. Excavating iron ore (no further information given.) Anonymous Chinese album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 119, pl. 3.

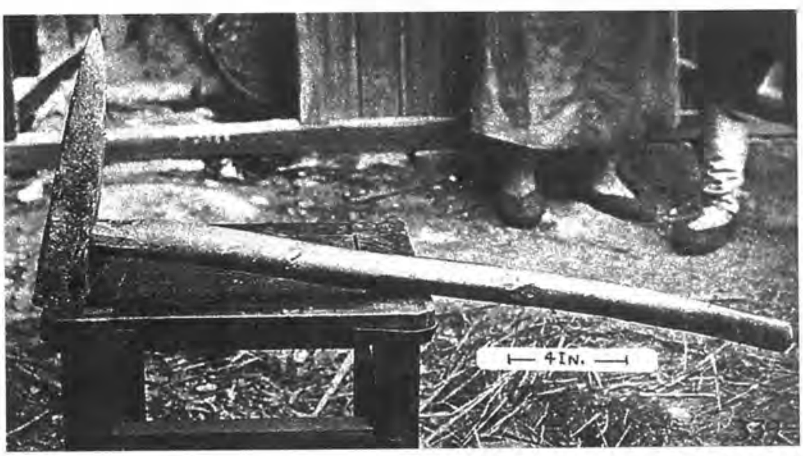


Fig. 61. Coalminer's pickaxe, just over 60 cm long, used for digging and enlarging shafts. From Kiangsi in the 1920s. Hommel (1937), p. 7, fig. 11. A similar pick, weighing about three kg (six pounds), was use by coal miners in Taiwan. Brown & Wright (1981), p. 66.

Fig. 62. Miners opening a new coal mine. Note the miner on the left with a digging stick who is probably working on relatively soft earth while his fellow miner on the right is attacking rock with a gad and mallet. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 117, pl. 9. (Compare Fig. 22 and Fig. 58.)

(3) Shafts, Adits and Drifts

In the earliest stages of underground mining, the technique of working down from the surface by means of vertical or steeply inclined shafts seems to have predominated in mining everywhere. The nature of the deposits was the key determinant here: the outcrops that the early miners discovered at the surface and then followed underground were typically more vertical than horizontal (Fig. 62).[42] Even when the ore appeared in basically horizontal deposits, as with the flints at Grimes Graves in England, a relatively level terrain might make mining by means of vertical shafts

[42] Thus, Slessor (1927, p. 60) notes that true 'vertical openings' were extremely rare in Chinese native workings since shafts typically followed the ore wherever it led.

followed by horizontal excavation in the ore-bearing stratum the only option.[43] It was only when relatively horizontal deposits were accessible from hillsides that the miners could work deposits directly from the surface by means of a more-or-less horizontal adit.[44] In China, such conditions were relatively common in the case of coal deposits[45] but extensive underground mining of coal occurs in China only long after the development of earlier forms of underground mining.

The strong reliance on vertical shafts in early mining can be seen very clearly at Thung-lü shan 銅綠山 where we find a multiplicity of such shafts with relatively few and only short horizontal drifts leading off them.[46] As long as the miners were still working shallow deposits (and had not yet worked out effective ways of supporting excavations against collapse), it was apparently easier and safer to rely on many shallow shafts that might be worked for as little as 100 days or so.[47] This tendency may also be reflected in the prolific use of vertical shafts within the mine, at least at Thung-lü shan. Besides the shafts that connected directly with the outside, there were also a large number of vertical shafts that led down from the floors of the galleries. These shafts originating underground (*mang ching* 盲井, literally 'blind shafts') or winzes could have served a number of purposes: exploring the extent of the deposits, searching for new pockets of ore, storage of water. In some cases, they may have connected galleries on two levels, but the excavations have not yet established this clearly.[48]

The procedure of working steeply downward from the surface was largely unavoidable,[49] but it got mining off to a bad start: most of the tasks of mining become

[43] This method was frequently used thoughout Chinese history especially but not exclusively with bedded deposits such as those of coal and iron. Vertical shafts with galleries radiating out from them seem to have been the norm at the tin mines of Ko-chiu in the 1870s; de Kergaradec (1877), p. 540. Tegengren (1924, pp. 164, 168) described the typical practice in the iron mines of southern Shansi early in this century: 'The method of mining may be briefly described as follows. From the bottom of the shaft, being about 1.0–1.5 m in diameter, drifts are started in various directions, following the ore bearing layer which mostly lies nearly horizontal. The drifts are very narrow and the height is only from less than 1 m to 1.2 m. The horizontal width hardly allows a broad-shouldered man to enter. The forming of large open rooms is generally avoided owing to the danger from a caving roof; as a rule the drifts are winding according as the best ore has happened to be struck. The length of a drift depends on the lateral extent and quality of the ore; it seldom exceeds 100 m owing to the increasing difficulties for a creeping man in hauling the ore baskets to the shaft. Several drifts are started from one shaft and when the mining becomes too difficult or unprofitable the mine is abandoned and a new shaft sunk.'

[44] 'Adit' is commonly used to refer to a tunnel with only one opening to the surface. Typically, an adit is not completely horizontal but slopes downward toward the opening in order to facilitate haulage and drainage. But conditions were not always right, and many Chinese 'adits' (using the terminology commonly employed by Western observers from late in the last century to the early part of this century) slanted down from the opening by as much as 45°; Anon. (1910), p. 762. Tegengren (1924, p. 164) writes of 'inclined adits with steps modelled out in the clay-shale' in the coal mines of southern Shansi.

[45] Treptow (1918), p. 174. Hosie, writing about Szechwan coal mining, comments that '[v]ertical shafts are unknown, horizontal galleries being simply driven into the hillsides.' Hosie (1922), p. 171.

[46] Yang Yung-kuang *et al.* (*1980–1981*), p. 88. [47] *Ibid.*, p. 82.

[48] In places, there could be as many as three blind shafts or winzes sunk into less than ten m of gallery; Hsia Nai & Yin Wei-chang (*1982*), p. 4.

[49] At the western Han Chin-niu 金牛 mine at Thung-ling, where excavations disclosed two working levels separated by about two metres, the excavators are convinced that the lower level was worked first, and was then used for debris from the upper level; Yang Li-hsin *et al.* (*1989*), p. 917.

significantly easier if one starts from the bottom and works up.[50] R. J. Forbes argues for a general shift in mining techniques among the 'ancients' (in the West) in which the tendency was for adits to replace shafts as the standard method of mining excavation.[51] By contrast, Biringuccio distinguished mining by means of adits driven deep into the lower levels of a mountain, as practised by 'the moderns' of his day (early and middle +16th century), from that of the ancients who 'began the mine in the upper part of the mountain where the ore appeared in light of day at the surface, and digging down as in wells . . . followed it to the bottom, now here, now there, as it appeared.'[52] In any case, where working a mine by means of adits replaced reliance on shafts, it undoubtedly resulted from the many clear advantages of adits, especially in haulage and drainage since adits eliminated the need for costly hoisting equipment.[53] Adits also allow for easier entry and egress of the miners and turn out to be somewhat easier to ventilate than shafts.[54] There is some evidence, for example, at the Thung-lü shan and Thung-ling copper mines, that the Chinese were beginning to discover and act on these advantages of adits at least by the Warring States period.[55]

Nevertheless, adits were not without their shortcomings. One had to be fairly confident in hitting a deposit that would pay at depth in order to incur what could be the considerable costs of driving an adit through non-paying rock.[56] Except in the case of large, regular deposits (such as the coal beds of Shansi),[57] such confidence did not come easily in China with its preponderance of irregular, and therefore

[50] Smith (1967), p. 143; Young (1970), pp. 155–6. The choice here is not limited to shafts OR adits. Inclined or even vertical shafts could be driven to the bottom or at least a lower point in an ore deposit, after which working could commence from the 'bottom' up.

[51] Forbes (1963), p. 115. Note however that Forbes speaks of 'driving horizontal adits . . . following the veins'. Again, this would be possible only in the minority of deposits where an outcrop on a rocky slope would lead to a mainly horizontal vein.

[52] Smith & Gnudi (1959), p. 19.

[53] Vogel (1991c), p. 77; Young (1970), p. 154. Quite possibly, some of the inspiration came from the use of tunnels even in open-pit workings where they could be useful in connecting one trench or pit with another (Bromehead (1940), p. 102) though I know of no evidence as yet that such tunnels were actually used in early Chinese open-pit mining.

[54] Smith & Gnudi (1959), p. 19; Anon. (1907), p. 1220. The flowing water of drainage adits draws air with it, thereby assisting ventilation; Morrison (1992), p. 124.

[55] Yang Wen-heng (*1978*), p. 306; Yang Li-hsin *et al.* (*1989*), p. 918. Cf. also Yang Yung-kuang *et al.* (*1980–1981*), *passim* which suffers however from idealisation in the sketch drawings and a tendency to read modern mining practices back into the Thung-lü shan evidence. This leads them, for example, to overstress the distinction between vertical and inclined shafts, seeing the latter as a major technological advance (p. 89). It is more likely that we are dealing here with a continuum where the general adoption of technological improvements – as opposed to practices devised *ad hoc* to respond to the particular challenges of a specific excavation – occurred very slowly, not to say imperceptibly.

[56] This principle is still relevant in modern prospecting. As a standard manual on mining notes: 'If the prospector wishes to do some development work, it is a good rule to follow the ore. Where the topography permits, it is a temptation to drive a long adit to cut the vein at depth. Such a procedure is costly and time consuming, and the vein at the adit level may pinch out, be faulted or barren, and little or no information is gained. By sinking a small shaft in or along the vein, definite information regarding the deposit is obtained.' Lewis (1964), p. 278.

[57] Shockley (1904), p. 865, noting adits that had been worked for 70 or 80 years and extended 7–8 *li* (c. 3–4 km) into the mountain; Reid (1901–1902), p. 31, describing an adit in a coal mine near Chungking that was more than 6 km long.

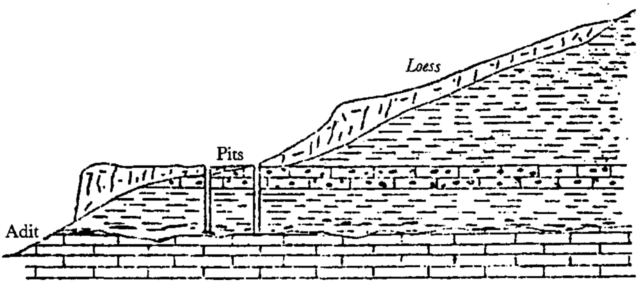


Fig. 63. Diagrammatic section of strata in southern Shansi. Large and extensive deposits were not synonymous with accessibility by native methods of mining, as shown by the ubiquitous iron ores of Shansi. Because of the hilly terrain with the iron formations frequently covered by thick layers of loess or coal measures, only narrow strips along the slopes of hills were typically accessible to mining by pits, shafts or adits. Based on Tegengren (1924), p. 162.

highly unpredictable, deposits.[58] Indeed, even with the most sophisticated modern geological knowledge, it is impossible to predict on the basis of general ideas what will happen to a vein at greater depths.[59] Even where one could be quite certain of the existence of a substantial deposit, as in the case of many coal mines, the highest anticipated profit from the sale of the mineral might well fail to justify investment in the digging of an adit.[60] The late 19th century reformer, Chang Chih-tung, who had a great deal of hands-on experience in establishing modern enterprises in areas under his jurisdiction,[61] even generalised that: 'The major failing of native mining methods is that excavation by means of sloping [adits] precludes mining at depth (*hsieh chhuan erh pu neng shen ju* 斜穿而不能深入).'[62] The idea seems to be that the cost of driving adits limited the depth to which they could penetrate. Tegengren has provided an excellent illustration of how native mining methods limited access even to large and extensive deposits (Fig. 63).

[58] Interestingly, von Richthofen in describing mining in the area east of Thai-yuan 太原 shows how even the rich coal deposits of Shansi could present what in effect were ideal conditions for the use of shafts in preference to adits: 'Experience has taught the inhabitants, that a good sort of anthracite can only be got in those places where it is covered by at least a few hundred feet of rock. *Notwithstanding the numerous out-croppings of coal beds on the hill sides*, the mines (at least all those which I have seen) are therefore worked by vertical shafts. They descend to the depth of from 50 to 300 feet, and some of them are said to have been in use for upwards of a hundred years. All the mines are dry, as the coalbeds are naturally drained. The thickness of the coal varies ordinarily from 12 to 20 feet, and in some mines attains 30 feet. Mining is very easy and cheap. The roof of that coalbed to which most shafts descend is a hard sandstone; a few pillars and walls of coal are sufficient to sustain it. All the rest of the coal is extracted.' von Richthofen (1875), p. 19, italics added.

[59] Pearl (1973), pp. 274–6.

[60] Thus Shockley: 'The Chinese nearly everywhere prefer the sinking of a shaft to the driving of an adit more than a few hundred feet long.' Shockley (1904), p. 849. Contrast this, however, with Tegengren's account of cinnabar mining in Kweichow and neighbouring parts of Szechwan and Hunan where steep escarpments as well as the presence of mercury not far from the surface made adits the exclusive method of excavation (Tegengren (1920), p. 17), and with the adits into the coal beds of Shansi just mentioned.

[61] His efforts at Wu-han won for that city the sobriquet of a 'Chinese Chicago'; Teng & Fairbank (1954), p. 166.

[62] Wu Chheng-ming and Hsu Ti-hsin (*1987*), Vol. 2, p. 677. Actually, a great deal of coal mining in China at this time was carried on by means of shafts rather than adits; Anon. (1898–1899), p. 642; Shockley (1904), p. 849.

Fig. 64. Ladders in a 'blind shaft' of a gold mine at Ku-phao 古袍, Kwangsi. Rope ladders seem to have been relatively rare in Chinese mines. Certainly, there is no evidence for anything as elaborate as the ladders used in the +16th century Bolivian silver mines of Potosi, 15–20 m long 'with three twisted leather ropes like hawsers, with stepping sticks placed between them, so that at the same time, a man can go up and another down it.' For this citation and an illustration, see Crozier (1994), p. 3. Original photo, 1994.

Lack of timber could also preclude the use of adits. According to von Richthofen's 19th century account, the mines that lined the hillsides along the river at Po-shan in northern Honan (and which were therefore well situated for working by means of adits) were almost exclusively shaft mines because of a lack of timber to provide supports for adits.[63]

More than true vertical shafts or very slightly inclined adits, Chinese miners in actual practice seem to have opted particularly often for shafts inclined at an angle of around 40–45°.[64] These could be found in a great many mines across China, from the coal mines of Shansi and Hopeh to the tin mines of Yunnan.[65] Such inclined

[63] von Richthofen (1898), p. 444; Wright (1984), p. 6. By contrast, the similarly situated gold mines of western Kwangsi in the gold belt lying between Kuei-lin 桂林 and Wu-chou 梧州 have been ordinarily worked by adits in part because the hard country rock tends to minimise the need for timbering.

[64] Inclined shafts were also preferred in central Europe in the time of Agricola; Hoover & Hoover (1912), p. 120.

[65] di Villa (1919), p. 90; Edkins (1867), p. 246; Collins (1909–1910).

Fig. 65. Stulls used as a ladder in a gold mine in western Kwangsi. Original photo, 1994. Cf. the statement in the *Tien-nan Hsin Yü* (p. 6) referring to salt mines in Yunnan: 'They enter by climbing down timbers set in place like ladders (*chia mu ju thi erh hsia chi* 架木如梯而下及)'.

shafts offered shorter distances to be excavated in order to arrive at the coal or the ore body. At the same time, they could be finished with steps for easier entry and egress and, possibly, haulage.[66] Von Richthofen described an interesting variation on inclined shafts that he saw in the Ta-thung 大同 coal field in Shansi. The shaft was 'in the curious shape of a spiral, and provided with stairs. It is used for the extraction of coal, and large enough that one line of men coming up with coal can conveniently pass the line of others who go down with empty buckets.[67]

Insofar as one can generalise, then, about the use of vertical shafts, shafts of greater or less incline, and adits in Chinese mining, it is probably safe to say that any

[66] de Villa (1919), p. 90; Dawes (1891), p. 335; Treptow (1918), p. 174; Tegengren (1924), p. 164 ('inclined adits' = 'inclined shafts'?). Dawes noted that stulls (individual timber props) could also be placed in shafts to serve as ladders, a method he found to be better than the notched poles used by Mexican miners both for speed of movement and for allowing the carrying of heavy loads. Neither advantage would seem to hold for this method as one sometimes sees it employed in the gold mines of western Kwangsi (Fig. 65). For ladders used in Chinese mines, see Fig. 96 where the *lung i lou thi* 攏夷樓梯 looks as if it just might be a notched tree trunk and Fig. 64 which shows both a rope ladder with wooden cross members and, below it, a regular wooden ladder.

[67] von Richthofen (1872b), p. 18. Such spiral shafts were also to be found in the coal mines west of Peking: 'The descent into the pit is by a spiral shaft, about a hundred yards down, and through a trap-door, used for diverting currents of air.' Mossman (1867), p. 210. Compare the shaft at Schemnitz described by Agricola where the horses used to power three pumps went down into the mine by means of 'an inclined shaft, which slopes and twists like a screw and gradually descends.' Hoover & Hoover (1912), pp. 194–5. Spiral shafts have also been found in Roman mines; Forbes (1963), pp. 194–5.

preference by Chinese miners for the use of one or another of these possibilities answered to a whole range of geological, economic and technological considerations, among which the first two tended to predominate. But whether the miners opted for shafts or adits, even the limited information on the depths reached in traditional mines demonstrates impressively their ability to work deposits deep underground (Table 13 and Table 14). At Thung-lü shan 銅綠山 in Warring States times, for example, miners began to use a 'cut-and-fill' technique in which vertical or inclined shafts were driven directly to the base of the ore body. Two-level drifts were then excavated and timbered, with the somewhat smaller upper drift sitting on the larger lower drift. Ore could be cut, sorted and dressed on the upper level, with the lower level used for waste filling and transport of the dressed ore.[68] It has been suggested that this practice 'greatly improved the safety of mining'[69] but one may be permitted to wonder whether such complex excavations could not, at least under certain conditions, just as easily have made mining more dangerous.[70]

Deep underground mining also raises formidable problems of underground surveying.[71] Although surveying could be important both for establishing clear ownership boundaries as well as for the organisation of mining operations, it was 'one of the most recondite and demanding of engineering arts, and it is hardly too much to say that celestial navigation or topographical surveying is virtually child's play in comparison.'[72] In Europe, the sources have nothing to say about mine surveying until the time of Agricola, the early +16th century.[73] From that time on, however, mine surveying made great strides forward: descriptive geometry was used from early in the +16th century in the drafting of mining maps; trigonometry was incorporated into surveying methods toward the end of the century; and, throughout the century, the compass was used increasingly in mine surveying though it is hard to say how extensively.[74]

The silence of traditional Chinese sources on techniques for underground surveying together with frequent accounts of miners' disputes over who had the right to work a given section of a deposit suggest that surveying was rarely if ever used in Chinese mines.[75] Conflicting claims underground were ordinarily solved on an

[68] Alternatively, where firesetting was employed, the upper drift could also be used as the exhaust path for the smoke, thus enabling the miners to return to their work in the lower drift more quickly.

[69] Zhou Baoquan *et al.* (1988), p. 126.

[70] In the case of Thung-lü shan, the absence of evidence of cave-ins that trapped or crushed miners suggests that these mines were in fact quite safe, especially given their depth and extent. It is surprising to find this to be the case so early in the history of major mining excavations.

[71] The first Chinese maps to indicate the location of deposits and mines date from at least the Han and perhaps the latter part of the Chou; Biot (1851), Vol. 1, p. 377; Huang Yü-heng & Ai Ta-chheng (*1989*), p. 18. This was only one of many kinds of maps that were already in use in China at this time; Vol. 3, p. 534.

[72] Young (1970), p. 80.

[73] Checkland, in commenting on the 'dog's-leg irregularity' of a 1,310 m Roman adit in southern Spain, suggests that 'the Romans, working without the magnetic compass, seem to have had difficulty [with surveying]'; Checkland (1967), p. 46.

[74] Vogel (1991c), p. 77; Vogel & Theisen-Vogel (1991), p. 43; Palme (1990), pp. 40–1. Palme notes that the paucity of references to the compass in the texts of this period can be partly accounted for by the risk run by those who used it that they would be accused of practising magic or witchcraft.

[75] This seems to have been true for native mines well into the 20th century; Tegengren (1921), p. 15.

Table 13. *Shaft and adit depths in traditional Chinese metal mines*[a]

Location	Type	Period	Max. Depth (ft.)	Reference	Comments
TIMNA, SINAI	COPPER	c. −1000	100	CHOU WEI-CHIEN *et al.* (*1990*), p. 21.	36 m.
Hupeh, Thung-lü shan	Copper	−5th(?)	150	Hsia Hsiang-jung *et al.* (*1980*), p. 24; Ho Ping-chang (*1984*), p. 644.	50+ m.
LAURION	LEAD/SILVER	−5TH	300+	BROMEHEAD (1956), p. 2; Shepherd (1993), p. 16.	DEEPEST SHAFT: 117.6 m (150 m?)
Hunan, Ma-yang	Copper	Warring States	240+	Hsiung Chhuan-hsin *et al.* (*1985*), pp. 116–7.	c. 80 m vertical depth; nearly 140 m inclined depth.
S. Shantung/ N. Kiangsu, Hsu-chou	Copper	Han	300+	Wang Chung-shu (1982), p. 105.	100+ m.
Hopeh, Chheng-te-chuan-chü	Copper	Han	300+	Lo Phing (*1957*), p. 22.	100+ m.
RIO TINTO	SILVER	ROMAN EMPIRE	650	BROMEHEAD (1940), p. 111.	
Kiangsi, Po-yang	Gold	Chin (+4th)	75+	Lin Shou-chin (*1955*), p. 118.	10+ *chang*.
Su-chou area	Copper	Sung	200+	*Thai-Phing Huan Yü Chi*, ch. 91, p. 11a; Hartwell (1963), p. 53.	
Kwangtung, Shao-chou	Copper	Sung	800+	Yang Wen-heng (*1978*), p. 307; Chhi Hsia (*1987–1988*), v. 2, p. 546.	70–80 *chang*.
Fukien, Sung-hsi	Silver/Copper	Sung	300+(?)	Chhi Hsia (*1987–1988*), v. 2, p. 546, citing *Yun Lu Man Chhao*, ch. 2.	Several tens of *chang*.
Szechwan, Thung-shan	Copper	Southern Sung	2–300(?)	*HPC*, ch. 8, p. 8a.	Several tens or hundreds of *chang*.
Heilungkiang, A-chheng hsien	Iron	Chin (+12th)	125+	Hsia Hsiang-jung *et al.* (*1980*), p. 224.	40+ m.
Honan, Chhin-ling	Gold	Ming	300+	Li Ching-hua (*1981*), p. 78.	100+ m.

Table 13. *(cont.)*

Location	Type	Period	Max. Depth (ft.)	Reference	Comments
Chekiang	Silver	Ming	400+	Chhueh Liang-chhing (*1978*), pp. 102–3.	
CENTRAL EUROPE	SILVER/COPPER	c. +1500	600+	PACEY (1992), p. 105; NEF (1952), p. 467.	MAX. DEPTH REACHED AT SCHNEEBERG IN SAXONY. MOST SILVER OR COPPER MINES AT THIS TIME ONLY TO DEPTHS OF c. 75–80 ft (25 m).
RÖHRERBÜHEL (KITZBÜHEL)	SILVER/COPPER	+1618	2,906	KELLENBENZ (1974), pp. 201–2.	*HEILIGER GEIST* SHAFT, AT 886 m, FOR THREE CENTURIES DEEPEST IN THE WORLD.
Hunan, Ma-yang	Cinnabar	Chhing	c. 3500	Hsia Hsiang-jung *et al.* (*1980*), p. 313.	
Taiwan	Gold	19th	130	Davidson (1903), p. 465.	
Kwangtung, 'Koo-teen' (90 mi. NE of Canton)	Iron	19th	120	Gray (1878), p. 357.	Private mine worked for some two centuries.
Yunnan, Kung-shan	Lead/Zinc	19th–20th	800	Bain (1933), p. 165.	
Honan, Chhang-sha	Lead/Zinc	19th–20th	800	Bain (1933), pp. 164–5.	
Mongolia	Silver	1900	400	Woo (1902), pp. 755–6.	Dynamite introduced in 1889.
Yunnan, Ko-chiu	Tin	1900	3,000+	Collins (1909–1910), p. 188.	
Kweichow, An-nan	Cinnabar	1900	4,500	Weng Wen-hao (*1919*), p. 203; Tegengren (1920), p. 17.	T. cites Leclère that this was an adit and, at 1500 m, the limit for native methods.
Hopeh, 'Mi Yun' (NE of Peking)	Gold	20th	300	diVilla (1919), p. 86.	Gold with silver and copper pyrites.
Hopeh(?), 'Ku Shan Tsu'	Silver	20th	850	Bain (1933), p. 163.	Citing Hoover. Native methods, using modern pumps.

[a] Selected depths achieved in non-Chinese mines added in caps for comparative purposes.

Table 14. *Shaft and adit depths in traditional Chinese coal mines*[a]

Location	Period	Max. Depth (ft.)	Reference	Comments
Honan, Ho-pi shih	Sung	c. 150	Anon. (*1960*).	46 m Round shaft, 2.5 m diameter.
Honan, Chang-te	Ming	3,000(?)	Wang Chung-lo (*1956a*), p. 29.	As deep as several hundred *chang*. All coal below the water table.
Kiangsu, I-hsien	Late Ming/ early Chhing	600	Chao Chheng-tse (*1985*), p. 63.	30–60 *chang*.
Hopeh, Feng-jun	Late Ming/ early Chhing	450–600	Chao Chheng-tse (*1985*), p. 63.	Vertical shafts. If coal was not found after exploratory shafts reached 300–450 ft (100–150 m), the shaft was abandoned.
ENGLAND	c. +1700	c. 350	WRIGHT (1984), p. 6; HOLLISTER-SHORT (1976), p. 163.	C. 120 m MAXIMUM DEPTH IN BRITISH COAL MINES AT THIS TIME.
Anhwei	+18th	c. 250	Wang Chung-lo (*1956a*), p. 29.	
Chiekiang, Chhang-hsing	+18th	1,000+	Lü Tai-ming (*1986*), p. 129.	Reached by adits up to a mile long (2–3 *li*).
ENGLAND	c. 1800	900	WRIGHT (1984), p. 6.	300 m. SHAFT DEPTHS MADE POSSIBLE BY APPLICATION OF STEAM POWER TO PUMPING.
Hopeh, 'Mun-ta-kau' (Men-thou-kou?)	1863	8,500 (!)	Pumpelly (1870), p. 296.	'. . . worked to a horizontal distance of 8,500 feet'. Equipped with 'a very large fan-blower'.
Shansi	19th–20th	150–300	von Richthofen (1875), p. 19; Shockley (1900), p. 603; Shockley (1903), pp. 849, 865; Tegengren (1924), pp. 165–6.	Shaft depths typically under 100 ft (30 m). (Tegengren). Adits up to 3,000 ft 1000 m or more.
N. Hopeh-Liaoning	19th–20th	200–400	Moller (1909–1910), p. 473.	No 'mechanical means' used.
Hopeh, Men-thou-kou	1930	400+	Steward (1930).	No mechanical power whatsoever.
Shantung, Po-shan	1900	240	von Richthofen (1898), p. 444.	About the maximum possible with existing winding gear.
Shantung, Wei-hsien	1900	180	Anon. (1908c).	

[a] Selected depths achieved in non-Chinese mines added in caps for comparative purposes.

ad hoc basis as they arose, drawing on generally accepted rules that had nothing to do with the drawing of boundaries. As V. K. Ting summarises the situation early in this century: '[In most Chinese mines,] underground boundaries were entirely unknown . . . Once the mineral has been found, the miner follows it up without the slightest idea of its direction. The very general rule for settling disputes is that "when two miners, each working in his own shaft, see each other's light, they should both leave off the communication and change their direction of working".'[76]

Only occasionally do we get some idea of what the Chinese were able to accomplish when they made the effort to develop a mine according to a plan. For example, Alexander Reid, writing at the very beginning of this century, tells of a mine that had been opened more than 90 years earlier and later abandoned: 'The timbering was intact, the props and bars in line as if they had been laid there but recently, and under the superintendance of a keen mathematical surveyor.' The result was an absolutely straight tunnel more than 1,500 m in length.[77] It would be interesting to know whether a compass was used in this or any other excavations. So far, we seem to have no evidence at all for the use of compasses underground.[78] This could be an even more striking example than gunpowder of the failure of the Chinese to apply one of their great inventions to the task of mining. If so, it would be all the more surprising given at least a certain amount of interaction between mining and geomancy.[79] Geomancers, of course, made extensive use of the compass in recent centuries.[80]

(4) Support of Excavations

Once mining proceeds underground, the likelihood is that some kind of wall or roof support will be needed before long. This was true even in the relatively shallow excavations of early mines since the very areas where mining was likely to be most feasible and successful were precisely those areas where unsupported underground workings would be most dangerous and perhaps even impossible. Rocks with the cracks and fissures that provide pathways for ore-bearing solutions will not typically be strong enough to be entirely self-supporting. Moreover, the movement of faulted

[76] Collins (1922), p. 248. One can appreciate the potential for conflict in a mining area like that of southeastern Shansi where Tegengren found in an area of some 2,000 square m a total of 72 shafts, or one shaft for every 28 square m! Tegengren (1924), pp. 165–6.

[77] Reid (1901–1902), pp. 33–4.

[78] At least by the mid-19th century, compasses were in use in Japanese mines (Treptow (1904), p. 5), though we do not know how often.

[79] See below, Section (*k*)(4).

[80] One probably important reason for the Chinese lag in developing surveying, though not for the failure to use the compass, was that geometry overall played a small rôle in traditional Chinese efforts to understand the natural world; Vogel & Theisen-Vogel (1991), p. 44. Moreover, there is also a significant question of attitudes that deserves to be explored here. Ziegenbald (1984, p. 48) makes the important point that people of the middle ages in Europe (and presumably in much of the early modern period as well), the period when mine surveying was making great advances, still did not expect the kind of exactitude we are familiar with. Pretty close was good enough. There is much to suggest that the Chinese felt even less any need to define mining claims with any kind of precision. (There was a stark contrast here to the emphasis that farmers placed on having their fields well-defined and marked.) To the extent that such an attitude prevailed, it hardly encouraged the development of surveying.

or folded areas, which also creates likely sites for ore deposits, tends at the same time to break up rock by crushing or grinding. Among other results, this leads to greater pressure on the mine roof than in undisturbed areas.[81]

Furthermore, early miners were limited by the simple tools at their disposal, and thus tended to focus their efforts precisely on those areas where the rock would be more friable and easier to excavate. One sees this pattern in many of the surviving remains of early copper mines in south central China, such as Jui-chhang 瑞昌 in Kiangsi, Thung-lü shan 銅綠山 and Kang-hsia 港下 in Hupeh, and Ma-yang 麻陽 in Hunan (Map 5).[82] Indeed, in part because of its geological conditions, south China seems to have been the stage for some of the earliest development of timbering techniques anywhere.[83] As early as the final centuries of the −2nd millennium, from about the mid-Shang, one can perceive the beginnings of a standardisation of timbering techniques that would lead not long afterwards to the prefabrication of support timbers outside the mines, after which they would be assembled in shafts and drifts that had been prepared for them.[84]

Such developments were preceded, however, by what must have been a slow and almost imperceptible evolution of shoring techniques beginning with efforts to prop up a weak wall here or a sagging roof there by jamming pieces of timber (stulls) rather erratically between roof and floor or wall and wall. Even these first, primitive efforts must have encouraged miners to experiment with simple ways of making the supports stronger and more durable. For instance, use of a headboard between the roof and the supporting pillar distributed the pressure more equally on the end of the pillar, helping to prevent splitting and therefore making for a stronger support. Evidence for this particular practice has survived from the Warring States period but it may well have been in use much earlier.[85]

In the narrow, somewhat inclined shafts of the kind that predominated in early underground mining, it is also good practice not to place stulls perpendicular to the dip but rather at an angle somewhat above the perpendicular so that downward movement of the hanging wall (the rock on the upper side of a vein or deposit) will not loosen but rather tighten the stull in place. It is just possible that Chinese miners of the Warring States period were beginning to comprehend this principle (Fig. 66).[86] Finally, the use of single timber props enabled miners to become familiar with the particular advantages of using wood, and certain kinds of wood, for supporting mine openings (timbering).[87] Wood, besides being readily available in most early mining districts, can easily be cut to fit as needed. It also possesses great

[81] Stoćes (1958), Vol. 1, p. 43. [82] Li Thien-yuan (*1988*), p. 33; Lu Pen-shan & Liu Shih-chung (*1993*).

[83] Pheng Shih-fan & Liu Shih-chung (*1990*), p. 26. [84] Lu Pen-shan & Liu Shih-chung (*1993*), p. 35.

[85] Lewis (1964), p. 40; Hsiung Chhuan-hsin *et al.* (*1985*), p. 119; Yang Yung-kuang *et al.* (*1980–1981*), p. 89.

[86] On the other hand, this practice has not been noted at Thung-lü shan where, however, there was some tendency for inclined shafts of lesser gradients to have their vertical timbers set a right angles to the horizontal plane while the vertical timbers of inclined shafts with a steeper gradient were set at right angles to the ceiling and floor; Barnard (1989), pp. 176–7.

[87] The miners had already begun acquiring familiarity with the strength and durability of different woods when selecting them to make their mallets, spades, ladles and other tools.

Fig. 66. Props or stulls in the Warring States copper mine at Ma-yang 麻陽, Hunan. Hsiung Chhuan-hsin *et al.* (*1985*), pl. 2, no. 1. Not all the props in this shaft were set at the same angle. There is a 10 degree angle of deflection between the prop in the centre and the one on the left. Although the team excavating this mine interpreted this as the result of the two props having been installed at different times, in between which the roof had shifted somewhat, Chinese miners may also have been in the process of discovering the value of placing props at an angle above the perpendicular to the dip so that a downward movement of the hanging wall or a sideways/ downward movement of the roof would further secure the prop in place instead of loosening it. For a similar development at Thung-lü shan 銅綠山, see Yang Yung-kuang *et al.* (*1980–1981*), p. 89.

strength and stiffness relative to its weight. Finally, it has some built-in safety factors such as its tendency to fail gradually and to warn miners of imminent failure by its audible cracking.[88]

As we shall discuss below, miners were by no means restricted to wooden timbers for supporting excavations. Other methods such as leaving unexcavated pillars of rock or ore, using bricks and stones to prop up roofs, and the filling in of worked-out areas with broken rock and low tenor ore have also been important, in China as elsewhere.[89] But it was clearly in timbering methods that the ingenuity of Chinese miners revealed itself especially clearly, and at an early period.

[88] Lewis (1964), pp. 38–9. Some long-grained woods such as aspen, fir, spruce, oak and chestnut are especially valued for their durability and/or for providing warning as they split under pressure. Miners at Jui-chhang 瑞昌 in the late –2nd millennium preferred oak and *nan mu* (楠木), a wood similar to cedar. Chestnut was also much favoured by early Chinese miners, and for good reason. In the copper mines of central China, chestnut timbers put in place as early as the Chou have often survived in good shape down to the present; cf. e.g. Hsiung Chhuan-hsin *et al.* (*1985*), pp. 113–14. By contrast, resinous woods such as pine decay rapidly in mines; Ure (1860), Vol. 3, p. 307.

[89] Hsiung Chhuan-hsin *et al.* (*1985*), p. 113; Li Thien-yuan (*1988*), p. 36; Robertson (1916), p. 269. Cf. Section (*h*)(5) below. These methods had the advantage of requiring little or no maintenance. Maintenance of timbers could be a costly problem, leading in worst cases even to the abandonment of workings that had not yet been fully exploited; Louis (1891), p. 640.

Successful timbering, as we have suggested, relied on considerable expertise that could be gained only by long experience. Judgements on whether support was needed, and how much, were often highly intuitive. Mistaken judgements or sloppy workmanship, perhaps resulting from excessive concern to keep costs down, could lead to cave-ins, with their resulting injuries and deaths, and perhaps even an end to further exploitation of the mine. Inefficient timbering could also increase the difficulty of mining operations, as when miners dared not replace old timbers but had to place new timber underneath or inside them, thus narrowing the openings through which they had to pass.[90] On the other hand, skilful excavation and support of a deposit could lead to long-term trouble-free mining. In the Warring States copper mine at Ma-yang 麻陽 in Hunan, the miners left in place a stratum of the orebody about 0.4 m in thickness, thus forming a strong roof that has largely resisted cave-in right up to the present.[91]

Many remains of timbering even from very early mines have recently come to light in China. They display a remarkable variety of techniques and have drawn considerable attention from archaeologists and historians of Chinese mining. A full and detailed account of all the various methods used could itself be the subject of a not-necessarily-small book. Here, we shall focus on the growing sophistication of timbering techniques during the –1st millennium, using as our prime example the especially rich and well-reported remains of the copper-mining complex of Thung-lü shan 銅綠山. Where necessary, the Thung-lü shan picture will be supplemented with information derived from other excavations, especially those at the Kang-hsia mine some 60 km southeast of Thung-lü shan and, increasingly in the years just this before this was written, at Jui-chhang 瑞昌 in the same area.[92] In this way, we shall be able to highlight the major developments out of which emerged the patterns that Chinese miners would return to again and again during the following two millennia.

In the earlier phase (before c. –500) of mining at Thung-lü shan, inclined and vertical shafts were generally quite small in cross-section, on the average approximately 50–60 cm square.[93] By contrast, shafts at Jui-chhang with a rectangular cross-section and dating from about the –14th century were already somewhat larger, measuring about 70–80 × 90–92 cm.[94] In some of the earliest shafts, which would have been inclined rather than vertical, weak areas were undoubtedly supported from time to time by round timber props (stulls) which might have pointed ends that fit tightly into

[90] Pumpelly (1866), p. 19. [91] Hsiung Chhuan-hsin *et al.* (*1985*), p. 113.

[92] For Kang-hsia, see Vogel (1991), based on Li Thien-yuan (*1988*) but calling into question (p. 162) the narrow and precise temporal range of –9th to –8th centuries proposed by the Chinese archaeologists. For Jui-chhang, see Lu Pen-shan & Liu Shih-chung (*1993*) and Liu Shih-chung & Lu Pen-shan (*1990*), both of which include good illustrations; and Chou Wei-chien *et al.* (*1990*), p. 20.

[93] Ho Ping-chang (*1984*), p. 644; Zhou Baoquan *et al.* (1988), p. 126. One finds similarly narrow shafts in the Neolithic flint mines of Spiennes in Belgium where, in spite of depths up to 16 m, the shafts seldom exceeded 0.5 to 1.0 m in width (Shepherd (1980), p. 16) and in Cyprus where shafts regularly were only 0.5 m square (Shepherd (1993), p. 17).

[94] Liu Shih-chung & Lu Pen-shan (*1990*), pp. 3, 11; Lu Pen-shan & Liu Shih-chung (*1993*), p. 35. Narrow shafts had the advantage that, if one side were provided with hand and toe holes, they could be climbed without a ladder by bracing the back against the opposite side; Checkland (1967), p. 44.

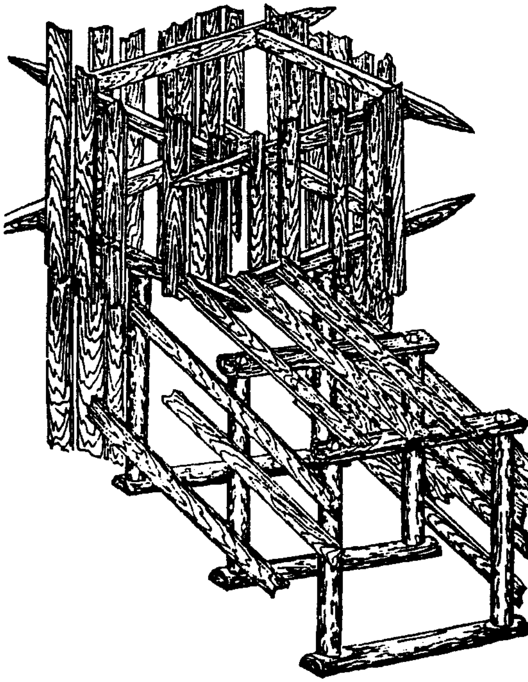


Fig. 67. Reconstruction of shaft and gallery timbering used at Jui-chhang in the early –1st millennium and showing the alternating mortise and tenon squares of the shaft as well as the use of both mortise and tenon (for roof timbers) and 'bowl-mouth' (for floor timbers) joints. Lu Pen-shan & Liu Shih-chung (*1993*), p. 36, fig. 6.

indentations made in the walls of the shaft.[95] When true vertical shafts came into use, more elaborate supports were needed that would brace all four walls of the shaft. This led to the invention of the first four-piece sets in Chinese mining. One version, from Thung-lü shan, consisted of two timber boards, about 10 cm across and pointed at each end for wedging into the walls. Not far from each end, a square mortise was carved out. Into these fit tenons fashioned on the ends of two round timbers about 6 cm in diameter that served as the crosspieces.[96] A variation on this method (Fig. 67) is seen in an undated but probably pre-Warring States (before –500) shaft at Jui-chhang.

[95] Rounded timbers are usually preferred for mine supports because they maintain the full strength of the piece of timber, some of which would be lost in squaring. On the other hand, the outer bark is usually removed since, by retaining moisture, it hastens the decomposition of the wood; Ure (1875), Vol. 3, p. 307. Chinese miners were regularly removing bark from timbers at least by about –500, and perhaps much earlier; Hsiung Chhuan-hsin *et al.* (*1985*), p. 119; Liu Shih-chung & Lu Pen-shan (*1990*), p. 4.

[96] Essentially the same method appears at the Jui-chhang mines in the early part of the –1st millennium; Lu Pen-shan & Liu Shih-chung (*1993*), p. 36. There, however, a different kind of joint, probably from a slightly earlier period, is also seen where tenons at both ends of the roof timbers fit into open slots at the top of the vertical timbers; *Ibid.*, pp. 36–7, esp. fig. 7.

Here, timber boards finished flat on the side facing the wall but left rounded on the inner face, and with a diameter of 12 cm, each had a mortise carved on one end and a tenon on the other so that four of the boards were formed by a kind of alternating interlocking system into a set.[97] Typically, these sets were separated one from the other by about 25–40 cm and were sometimes joined by means of smaller upright members tied to the sets by bamboo or rattan ropes (Fig. 68(*a*)).[98]

During the period after c. –500, the depth of shafts at Thung-lü shan increased from the earlier maximum of 20 or 30 m to as much as 50 and more metres. Pairs of shafts were sometimes sunk to serve a single mine, thus facilitating hoisting of men and materials as well as probably promoting better ventilation.[99] Both shafts and drifts also became slightly more 'spacious', averaging 100 × 130 cm and 130 × 150 cm respectively.[100] Improved tools in the Warring States period thus not only made for more effective excavation at the work face but also improved the working conditions of the miners by giving them more space in which to move, allowing them for example to walk from one part of the mine to another instead of crawling.[101]

The larger shafts were supported by stacking sets one on top of another. The sets themselves became more robust, using round timber about 15 cm in diameter. Instead of mortise and tenon joints or a method sometimes called 'bowl-mouth joints' *wan-khou chieh* 碗口結 used at Jui-chhang and in the Kang-hsia mine in which the ends of crosspieces were fitted into indentations gouged out of the timbers to which they were joined (Fig. 68(*b*)),[102] the later Thung-lü shan set timbers were joined in an overlapping or tongue-in-groove fashion by removing half of the ends of each timber and laying the downward facing indentations of one timber on top of the upward facing indentations of its two mates (Fig. 68(*c*)).[103]

A type of shaft timbering not seen at Thung-lü shan but important at the Kang-hsia mine represented another effort to provide adequate support for larger shafts. Instead of being square, the shaft opening was rectangular and a cross timber was added in the middle for further support (Fig. 69).[104] This structure would seem to be well

[97] Liu Shih-chung & Lu Pen-shan (*1990*), p. 4.

[98] Anon. (*1981*), p. 20; Hsia Nai & Yin Wei-chang (*1982*), p. 2; Liu Shih-chung & Lu Pen-shan (*1990*), p. 3.

[99] Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 95. On the value of paired shafts for ventilation, see below, Section (*h*)(10).

[100] Zhou Baoquan *et al.* (1988), p. 126. In general, the shaft dimensions at Thung-lü shan tend to be somewhat smaller than those of other, contemporary copper mines; Lu Pen-shan (*1990*), n.p. The dimensions of the largest drift or gallery found at Thung-lü shan were 1.6 m high by 1.95 m wide (mistakenly given as 1,950 cm in Zhou Baoquan *et al.* (1988), p. 126). This is significantly larger than the contemporary Greek mines such as Laurion where the galleries were never more than 1 m in height and were typically less than 1 m in width; Healy (1978), p. 81. The Thung-lü shan galleries are comparable to the larger galleries of Roman and medieval mines in the West which reached a maximum size of about 1.25 m by 2.5 m; Forbes (1963), p. 195.

[101] Ho Ping-chang (*1984*), p. 644; Chou Pao-chhüan (*1984*), p. 71.

[102] Liu Shih-chung & Lu Pen-shan (*1990*), p. 3; Vogel (1991), pp. 156–8; Li Thien-yuan (*1988*), pp. 34–5, 39. Bowl-mouth joints were also used to join crosspieces to pillars in galleries and stopes, as at the Ma-yang mines; Hsiung Chhuan-hsin *et al.* (*1985*), p. 119; pl. II, fig. 3.

[103] At the Chin-niu tung 金牛洞 mine (Thung-ling 銅嶺, Anhwei), essentally the same method was used. From the illustration provided by Yang Li-hsin, Yeh Po and Lu Pen-shan, it would appear that only the ends of *two* timbers from each set were cut away to join with the still rounded end of their mates; Yang Li-hsin *et al.* (*1989*), p. 913. The text says clearly, however, that 'the ends of *four* round timbers were cut to form step-like joints . . .' (*chiang ssu ken yuan mu ti tuan tian* (*chieh-tian*) *khan chheng thai-chieh chuang chieh-khou* 將四根圓木的端點(節點)砍成台階狀接口); p. 911, italics added.

[104] Li Thien-yuan (*1988*), pp. 33–4.

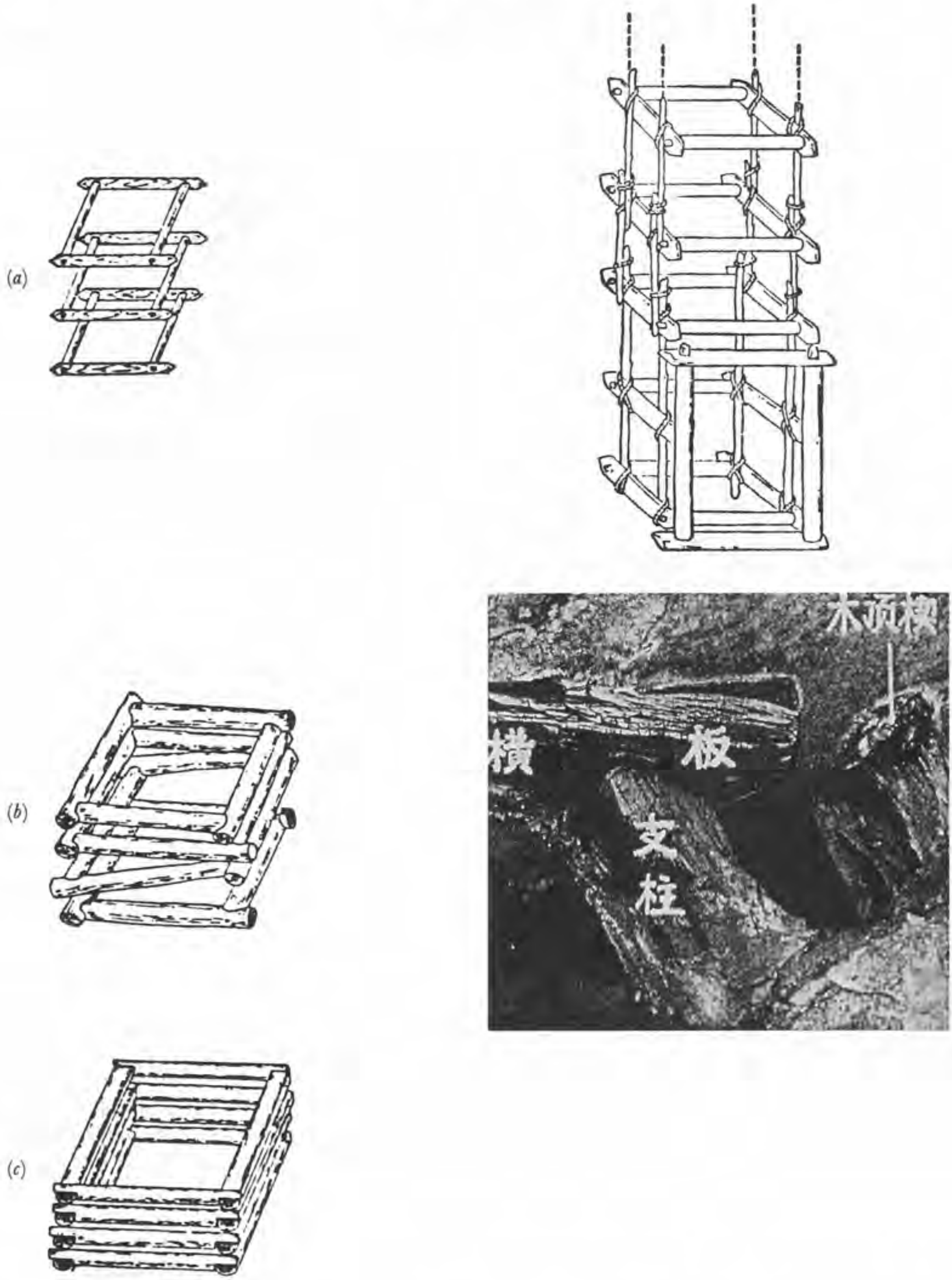


Fig. 68. Various methods for supporting shafts in early underground mining in China (not to scale). (*a*) Earlier method at Thung-lü shan 銅綠山. (*b*) Typical system used at the Spring and Autumn period mine at Kang-hsia 港下, Yang-hsin 陽新, Hupeh. The photograph (Hsiung Chhuan-hsin *et al.* (*1985*), pl. II, fig. 3) shows a support pillar (*chih chu* 支柱) locked by means of a 'bowl-mouth joint' (*wan khou chieh* 碗口結) into the horizontal roof beam (*heng pan* 橫板). (*c*) Later tongue-in-groove method at Thung-lü shan. (For descriptions and references, see text.)

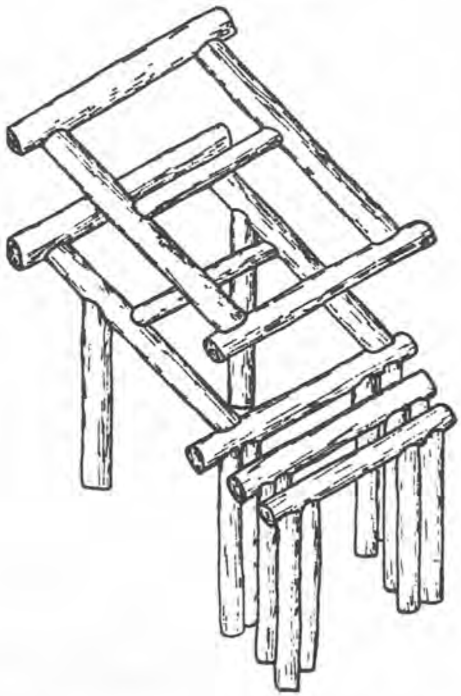


Fig. 69. Shaft sets with central reinforcing timber; from the Western Han copper mine at Kang-hsia 港下, Yang-hsin 陽新, Hupeh. Li Thien-yuan (*1988*), p. 34, fig. 5; Vogel (1991), p. 158. Chinese archaeologists have christened this style as 'sets in the shape of the character *jih* "sun, day"' (*jih tzu hsing* 日字形). The same 'bowl-mouth joint' (*wan khou chieh* 碗口結) construction was used by the end of the −1st millennium at the Thung-ling mines outside of Jui-chhang, but without the central reinforcing timber; Lu Pen-shan & Liu Shih-chung (*1993*), p. 34, fig. 2.

adapted to raising and lowering material or water simultaneously in each half of the shaft, but the excavation report gives no evidence suggesting this was actually done.[105]

The sets used to support roof and walls of level or almost level drifts or galleries were at first similar or even identical to those used in vertical and inclined shafts.[106] At Thung-lü shan, they tended to be spaced about a metre apart.[107] Gradually, however, significantly different methods of set construction began to appear, two of which are particularly striking. The first was the appearance of three-piece sets whose uprights could be sunk as deeply as necessary to obtain a firm footing. Here, the floor of the mine effectively took the place of the fourth, floor crosspiece (Fig. 70(*b*)).[108] A second method, to be found only in upright sets, depended on the fact that the main pressure on these sets would normally fall vertically on the cap or roof beam. Chinese miners therefore sometimes secured the cap timber by placing it in the

[105] It should also be noted that the excavators of the Chin-niu yung mine found a hint of the use of a middle, third prop to help support a cap beam that had probably been almost 3 m in length; Yang Li-hsin *et al.* (*1989*), pp. 911–12.

[106] Compare Fig. 68(*a*) and Fig. 69(*a*); see also Liu Shih-chung & Lu Pen-shan (*1990*), p. 3 for the same phenomenon at Jui-chhang.

[107] Li Thien-yuan (*1988*), p. 39; Hsia Nai & Yin Wei-chang (*1982*), p. 4.

[108] Depending on the solidity of the floor, the depth to which these posts were sunk at the Ma-yang 麻陽 mine varied from 20 to 30 cm; Li Thien-yuan (*1988*), p. 36. No matter how deep the vertical posts were sunk, however, these three-piece sets were weak compared with full four-piece sets.

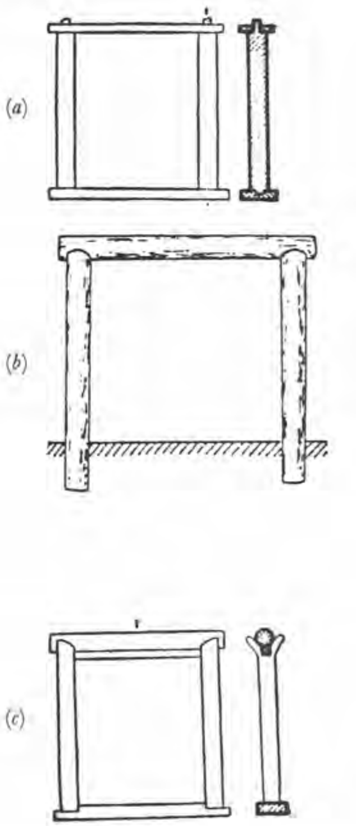


Fig. 70. Methods of supporting galleries or drifts in early Chinese underground mining (not to scale). (*a*) Earliest method at Thung-lü shan 銅綠山. (*b*) Three-piece sets used at the Spring and Autumn period mine at Kang-hsia 港下, Yang-hsin 陽新, Hupeh. (*c*) 'Duck's bill' method used at Thung-lü shan in the later Warring States or early Han period. (For descriptions and references, see text.)

crotch ('duck's bill' *ya tsui* 鴨嘴) at the upper end of forked timbers specially selected to serve as vertical posts (Fig. 70(*c*)). The notched sills would resist inward pressure at the bottom of the vertical posts while the ends of the cap timber would perform the same function.[109] Because of the greater pressures typically borne by drift sets, their timbers were often of a significantly greater diameter than the timbers in shafts. At Ma-yang 麻陽, timber diameters in drift sets averaged between 22 and 25 cm.[110]

Another approach to providing more substantial support for larger drifts that might be up to 2 m wide and over 1.5 m high,[111] was used both at Thung-lü shan and at Ma-yang, where a second horizontal timber was added for further support of the roof (Fig. 71(*b*) and (*c*)).[112] This procedure was especially to be seen at the junctures

[109] Li Thien-yuan (*1988*), p. 36; Hsia Nai & Yin Wei-chang (*1982*), p. 4.
[110] Li Thien-yuan (*1988*), p. 36. [111] Vogel (1991), p. 161. [112] Anon. (1980), n.p.; Anon. (*1975*), p. 5, fig. 7.

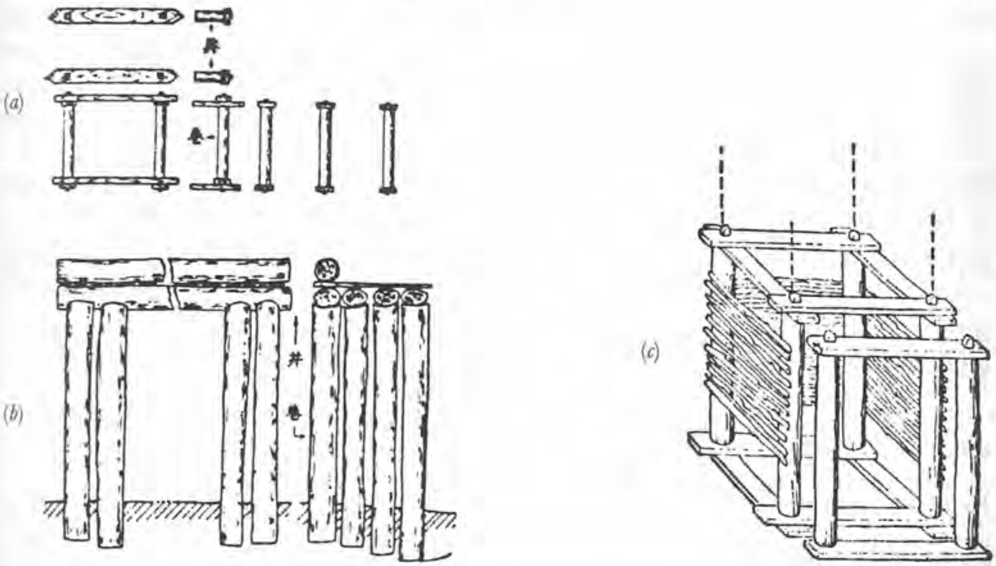


Fig. 71. 'Horse-head [i.e. 90 degree angle] entrances' at the juncture between shafts and galleries (not to scale). (*a*) Early version (Spring and Autumn period?) at Thung-lü shan 銅綠山. (*b*) Method used at Kang-hsia 港下, Yang-hsin 陽新, Hupeh. (*c*) Later method (Warring States) at Thung-lü shan. (For descriptions and references, see text.)

of shaft bottoms and galleries (the 'horse-head entrances' *ma thou men* 馬頭門) where a great deal of ingenuity went into the building of strong systems of supports.[113] The earliest type of juncture to be found at Thung-lü shan simply separated the lowest two sets of the shaft with vertical posts at each corner, linking the posts to the sets mortise-and-tenon fashion. These were possibly the earliest square sets in Chinese mining (Fig. 71(*a*)). Later versions of the juncture sometimes relied on what we might call an incomplete square set with only two rather than four floor sills (Fig. 71(*c*)).[114] A more primitive version, used at the Ma-yang mines, did not employ anything resembling a square set but simply supported the lowest set of the vertical shaft with upright timbers as the miners judged necessary (Fig. 71(*b*)).[115]

Along the roofs and walls, in the spaces between supports, various kinds of lagging were used to hold back rubble: boards (Fig. 67), branches, woven mats of bamboo or rattan. At Thung-lü shan, the walls were sometimes 'plastered' with a mixture of kaolin and straw.[116] Walls made of wooden boards were also used to seal off worked-out areas.[117]

At its best, the timbering in Chinese mines could be of a very high quality.[118] Indeed, Tu Fa-chhing and Kao Wu-hsun have commented on the regularity of the timbers excavated at Thung-lü shan and suggested that they must have been

[113] *Ma thou men* is a modern term; it does not appear in any dictionaries or traditional texts I have seen. Barnard suggests it is probably a local mining term; Barnard (1989), p. 175. Tu Fa-chhing and Kao Wu-hsun speak of two-tier horse-head entrances having been found, where the sill of the upper level forms the cap of the lower. They do not indicate, however, where they were found; Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 95.

[114] Li Thien-yuan (*1988*), p. 40. [115] *Ibid.*

[116] Liu Shih-chung & Lu Pen-shan (*1990*), pp. 3–5; Vogel (1982), p. 142. Cf. below, (*h*)(11).

[117] Li Thien-yuan (*1988*), p. 36. [118] Brown (1923), pp. 47, 114, 130, 131; Reid (1901–1902), pp. 33–4.

prepared outside the mine and then brought into it for assembly.[119] The rarity of human remains found even in early mines of some depth testifies to the effective use of timbering so that few miners seem to have lost their lives in cave-ins.[120] On the other hand, there were many cases where timbering was needed but was not used or was flimsy and insufficient.[121] Lack of skill does not seem to have been the problem; rather, it was the pressure exerted by extreme poverty to make economies of all kinds that was probably the main reason for taking dangerous shortcuts. Cost, including the cost of bringing timber in from ever greater distances, also helped stimulate experiments with other support methods, such as supports constructed of spoil,[122] that were less expensive, and which might also be easier to implement, more dependable and more durable.[123]

(5) Room and Pillar (Pillar and Stope) Methods[124]

In the long and very slow process of rationalisation of mining techniques, there is a clear tendency for excavations, be they shafts or drifts or stopes, to increase in size. We have seen one example in the shafts at Thung-lü shan. Larger working areas meant not only improved working conditions for the miners but also new opportunities to apply better methods. For example, once inclined shafts became large enough, the right kind of rock structure might permit miners to substitute pillars of rock or ore left in place during the course of excavation for more costly and perhaps less strong and durable timbering.[125] Chinese miners were experimenting with this practice at least as early as the second half of the −1st millennium. At the Ma-yang

[119] Tu Fa-chhing & Kao Wu-hsun (*1980*), p. 95. For an illustration of a pre-fabricated Roman mine-drainage wheel, meant to be assembled on site or even inside the mine, see Healy (1978), pl. 27 (between pp. 112 and 113). Also Weisgerber (1979), p. 75.

[120] Li Thien-yuan (*1988*), p. 38; Hsia Nai & Yin Wei-chang (*1982*), p. 4.

[121] E.g., Brown & Wright (1981), p. 67 (19th century coal mines in northern Taiwan); Tegengren (1921), p. 17 (20th century antimony mines in Hunan); Dawes (1891), p. 335 (19th century silver mines in Mongolia). It should also be noted that the Chinese apparently never devised a system of true square sets in which 'timbers were mortised and tenoned at the ends so that they could be fitted together to form hollow cubes, each cube interlocked with the next in endless series.' Cf. Paul (1963), p. 64, which notes, in any case, that this was a late (mid-19th century) mining invention in the West. For a contemporary illustration of this method, developed by Philip Deidesheimer, see Sloane & Sloane (1970), p. 31.

[122] As was also done, for example, by the Greeks at Laurion; see the excellent photograph in Healy (1978), pl. 11b.

[123] A striking example of how the provisioning of timbers grew increasingly costly is the Jui-yang 瑞陽 silver mine in Sung-chhi 松溪 hsien, Fukien, a deposit that was discovered in the first half of the +12th century. Within 20 years of the start of mining operations, the rich forests surrounding the mine had been completely denuded for a distance of 40 *li* (*c.* 20 km) from the mine in all directions; *Yun Lu Man Chhao*, ch. 2, p. 48.

[124] Although use of 'room' and 'stope' synonymously serves well enough for our purposes, this is actually a loose usage. A stope (probably a corruption of 'step') is, strictly speaking, an excavation above or below a level in a series of steps. It therefore refers usually to a highly inclined or vertical vein. By contrast, a room is a wide working place in a flat mine; hence, it is used most often in connection with coal mining where the coal beds tend to be more or less horizontal; Fay (1920), p. 652; Lewis (1964), chap. 16. In English coal mining especially, the common term is bord and pillar.

[125] Or pillars of coal; Reid (1901–1902), pp. 28–9, 36. Cf. also the von Richthofen citation in fn. 58 above. In general, whether using timbering or pillars of coal for support of excavations, methods in coal mines seem to have been very similar to those used in other kinds of underground workings; Lü Tai-ming (*1986*), p. 199.

copper mine in Hunan, rock pillars flaring at the top and bottom are used together with timbers to prop up excavations.[126]

In time, this evolved into the room and pillar (or pillar and stope) method that came to be used widely, especially in Chinese coal mines. We have good evidence for the use of this technique in the remains of a Sung/Yuan (c. +13th century) coal mine at Ho-pi 鶴壁 in Honan (some 25 km southwest of An-yang).[127] The miners first dug a main vertical shaft about 2.5 m in diameter and with rounded walls to a depth of about 46 m. Galleries were then dug in various directions to access and traverse the seam. The galleries near the main shaft were just over 2 m high and about 2 m wide but typical galleries (including four long ones that together totalled more than 500 m in length) were found to be something over 1 m high with a cross-section in the shape of a trapezoid 1 m wide at the roof and 1.4 m wide at the floor. After dividing the seam into small sections, excavation was carried out in two stages. In the first stage, coal was excavated from the remotest sections towards the main shaft, and from one of every two neighbouring sections, leaving the intact sections as natural props for the whole roof (the 'alternate squares method' *thiao ko shih* 跳格式). In the second stage the remaining sections were excavated with great care, again from the remotest towards the main shaft.[128]

By the later imperial period, when the cost of scarce timber led Chinese miners generally to an ever greater reliance on brick and stone for support of excavations,[129] room and pillar mining in one or another of its variations was the norm in most larger Chinese coal mines where it was especially suitable for working thick seams.[130]

We are not well informed on the actual techniques used by Chinese coal miners in connection with room and pillar excavations. One of the most important technical advances in coal mining built on the discovery that, by excavating coal at the foot of the seam, one could cause the coal above, now deprived of its support, to cave in of its own weight, thus greatly saving on the amount of cutting that had to be done by the miners. Some observers at the beginning of this century held that this practice was absent in Chinese coal mines. W. A. Moller claimed that miners in Manchuria had 'no idea of the advantages resulting from deep holing under the coal.'[131] The usually well-informed Herbert Hoover was adamant that 'to undercut the coal is a thing [the Chinese miner] has ever refused to embrace, preferring to cut straight from the face'.[132] Statements such as this make a good case for the claim that such excavation techniques could not have been common, at least in the

[126] Hsiung Chhuan-hsin *et al.* (*1985*), p. 123. The same procedure was also sometimes used at Thung-lü shan; Yang Yung-kuang *et al.* (*1980–1981*), p. 83.

[127] Anon. (*1960*); Yang Wen-heng (*1978*), p. 310; translated and slightly elaborated in Yang Wen-heng (1983), p. 310. The excavating teams estimated that this was a large coal mine by Sung and Yuan standards, perhaps employing several hundred men.

[128] Graham Hollister-Short suggests that this appears strikingly similar to coal mining practices in England (private communication). I suspect that might also be true for practices in other coal mining regions as well.

[129] von Richthofen (1898), p. 444; Bain (1933), p. 65.

[130] Wright (1984), p. 38; Reid (1901–1902), p. 27; Shockley (1904), p. 862. Thicker coal seams also led to the greater popularity of the room and pillar method in the United States than in Europe, where the seams tend to be thinner.

[131] Moller (1902–1903), p. 144.

[132] Hoover (1901–1902), p. 427.

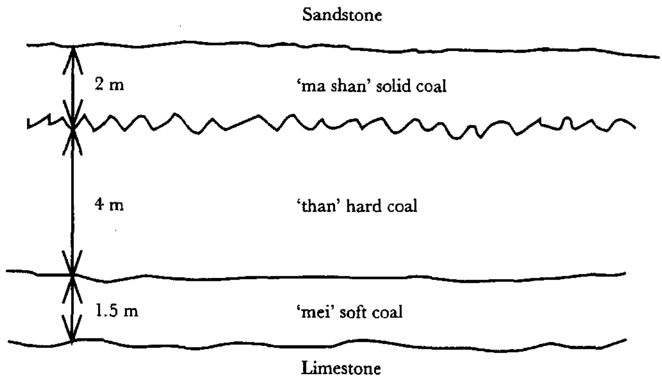


Fig. 72. Reconstruction of the coal seam at 'Ch'uan T'ai Shan' near Tse-chou 澤州 (Chin-chheng 晉城), Shansi. Based on Shockley (1904), p. 862. (Shockley speaks of the jagged edge that separated the 'ma shan' and 'mei' layers, but he must mean 'than' instead of 'mei'.)

areas with which their authors were familiar. But the fact is that some excavation of this sort was practised as least as early as the Ming.[133] At the same time Moller and Hoover were writing, William Shockley described in some detail a coal mine at 'Chhuan Thai Shan' near Tse-chou 澤州 in Shansi:

> A series of rooms, separated by from 10 to 20 ft of solid ground [coal] is opened. The size of the rooms varies from 15 by 20 ft up to 35 by 60 ft, depending on the character of the coal and of the sandstone roof, being larger with the harder coal. There are over a hundred of these rooms in the mine. The dimensions of the room having been decided on, a cut is made completely around it and is carried up to the 'ma shan,' [?] 16 ft from the floor (Fig. 72); at the same time the soft 'mei' [presumably 煤 'coal'] is taken out under this by a series of cuts 46 in. by 38 in. high. When the coal begins to crack – to 'talk,' as the miners say – they stop work in these drifts, and the block soon comes down, parting at the 'ma shan' seam, which is taken down later.[134]

Larger excavations also posed the question of what to do with worked-out areas. Where the development of mining operations permitted, they were frequently filled in with waste rock and low-grade ore.[135] This process had advantages that went beyond simply preventing cave-ins. It was a use for waste rock that obviated the need to hoist or haul it out of the mine. Filled in areas also automatically increased the ventilation of other areas where it was needed.

(6) Firesetting

We have stressed above (Section (*a*)(2)(iii)) the rigours of hardrock mining, with unremitting brute labour as often its most distinguishing characteristic. At its worst,

[133] Lü Tai-ming (*1986*), p. 197. [134] Shockley (1904), p. 862.

[135] For a schematic illustration of how this was done at Thung-lü shan, see Lei Tshung-yun (*1983*), p. 392, fig. 7. For a modern example, see Verschoyle (1906), p. 919 (turn-of-the-century gold mines on the northern coast of Shantung). Early uses of this method are discussed below in Section (*h*)(10).

hard and compact rock can be invulnerable to breaking solely by means of simple tools and muscle power. To get at the minerals in such ore bodies requires supplementary techniques that draw on the energy of natural forces.

The first of these techniques and by far the most useful in traditional times was firesetting. As Agricola commented, firesetting could make 'the rock . . . , however hard it may be, . . . so softened as to be the most easily breakable of all'.[136] Firesetting was as important for mining as the harnessing of water or wind power in other technologies. Not only did it permit a considerable saving of human energy but, apart from gunpowder and dynamite (which can in any case be seen as an extension of the firesetting technique), it was the only such development before massive mechanisation of mining in modern times.[137]

Firesetting appears early in the history of mining. In western Eurasia, miners had discovered its possibilities even in prehistoric times.[138] Chinese miners may have begun using firesetting as early as the later Neolithic period. At the large Neolithic stone toolmaking site at Hsi-chiao shan 西樵山 in Nan-hai 南海 county, Kwangtung, which extended over some 12,000 square m, a number of pits have been found, the deepest of which was excavated to a depth of 8.3 m. Because the stone into which the pits penetrated was extremely hard and compact, because the walls bore extensive signs of scorching, and because the bottom of the pits had considerable deposits of ashes, pieces of rock (some of which had scorch marks) and slivers that had peeled or been peeled off the wall rock, Huang Wei-wen and his colleagues concluded that firesetting must have been used extensively at these pits.[139] As Paul Craddock notes, firesetting is a technique that could easily be discovered by 'anyone who had observed the fate of a hard rock incorporated in a hearth'.[140] In any case, firesetting was certainly used extensively in Chinese mines by the Warring States period or the middle of the –1st millennium.[141]

Firesetting consists of heating the resistant rock face by building up a fire under or alongside of it and then either allowing the heated rock to cool naturally or subjecting it to rapid cooling by dousing it with a liquid (usually water, sometimes vinegar).[142]

[136] Hoover & Hoover (1912), p. 119. Indeed, quartz subjected to even a relatively low-temperature fire, could sometimes become so friable as to be disintegrated into a granular sand simply by crushing it between thumb and finger; Holman (1927), p. 221 and *passim*.

[137] For perhaps the best scientifically detailed overall discussion of firesetting, see Willies (1994).

[138] For earliest evidence of the use of firesetting in the West, cf. Shepherd (1993), pp. 20–4; Timberlake (1990), p. 52; Healy (1978), p. 85; Sandström (1963), p. 28; Clark (1952), p. 189; Davies (1935), p. 21; and Vol. 5, pt. 7, p. 533.

[139] Huang Wei-wen *et al.* (*1979*), p. 292. Only with the advent of metal tools would the quarrymen have some chance of extracting stone blocks from solid rock (as opposed to the earlier practice of using stone tools to shape natural boulders); Hodges (1970), p. 148; Hommel (1937), p. 12 (with illustration of Chinese quarryman's hammer, chisel and wedges).

[140] Craddock (1992), p. 1.

[141] Lu Pen-shan (*1990*); Liu Phing-sheng (*1988*), p. 54; Hsiung Chhuan-hsin *et al.* (*1985*), p. 122; Ho Ping-ti (1975), p. 189; An Chih-min & Chhen Tshun-hsi (*1962*), p. 140; Anon (*1959*), p. 69; Vol. 4, pt. 3, pp. 26, 278 and Vol. 5, pt. 7, pp. 538–40. By the late –2nd century, if not earlier, it was also used in the excavation of large, underground tombs. See the photograph in Wagner (1993), p. 337, fig. 7.1.1 which almost certainly shows the results of excavation by firesetting.

[142] For the largely though probably not entirely mythical special effectiveness of vinegar in this process, cf. Sandström (1963), pp. 28–9 and Shepherd (1993), p. 24 but also Vol. 5, pt. 7, pp. 534–5 and Young (1970), p. 61. The key point made in these latter references is that we cannot determine whether or not the vinegar might have added to the effectiveness of the technique unless we know the nature of the rock involved. As a weak acid, vinegar might effectively attack basic (alkaline) rock such as limestone or dolomite. Acid rocks such as quartz or

Fig. 73. Agricola's illustration of firesetting in a hardrock mine in +16th century Saxony. Hoover & Hoover (1912), p. 120. Note the shaving of the sticks and logs to facilitate kindling (top) and the miner leaving the working (lower right) while protecting his eyes and nose from the smoke of the wood that has just been set ablaze.

As a result of firesetting, 'a combination of the differential thermal expansion in the rock itself and of the vaporisation of entrapped water ensure[s] the disintegration of the rock into fractural layers . . .' (Fig. 73 and Fig. 74).[143] In optimal conditions, the ore subjected to this process can even be removed afterwards by hand without tools.[144]

porphyry would be immune to any special reaction to vinegar. Use of vinegar in place of water seems to have appeared independently in China, with the earliest surviving record dating to Thang times; Vol. 4, pt. 3, p. 278, fn. f. Paul Craddock, who has himself carefully studied firesetting and is familiar with recent experiments in this area, feels that 'no further useful shattering could be induced [by vinegar] after a night of burning.' (Personal communication, Jan. 20, 1992). Bjørn Berg strongly agrees; Berg (1992), p. 16, fn. 4.

[143] Craddock (1989), p. 183. See also Penhallurick (1986), pp. 71–5, which draws effectively on Collins (1892) (mistakenly referred to as 'Collins, (1973)' in n. 3, p. 78). Firesetting can also be used in quarrying (as it still is in Madras, India; Skinner (1969), p. 96); as a technique still used for mining jade when the toughness of jadeite renders more modern methods unsuccessful (Keverne (1991), p. 24); as an aid to the crushing of ores in the beneficiation process (as practised by Chinese gold miners in the 19th century; Louis (1891), p. 640).

[144] This was noted in a remarkable informative passage by the −2nd century Greek geographer Agatharchides in which he describes gold mining in Egypt; Hoover & Hoover (1912), pp. 279–80, fn. 8.

Fig. 74. Large galleries in Zawar Mala, Rajasthan, India excavated by firesetting and showing the smooth, non-angular walls that typically result from use of this technique. Craddock (1989), p. 184, pl. 8.5. Smooth walls resulting from firesetting could even impede the effectiveness of further use of the technique, requiring the walls to be roughened up before being fired again; cf. Penhallurick (1986), p. 74.

Firesetting had become a standard procedure in the copper mines of Chhu-chou 處州 (present-day Li-shui 麗水) in Chekiang by the Ming,[145] and is succinctly described by Lu Jung 陸容 in his *Shu Yuan Tsa Chi* 菽園雜記 (Miscellaneous Notes from the Garden of Pulses) of +1475:

In mining the copper, they first take large pieces of firewood of various lengths, stack them up against the ore-bearing earth, and set fire to them, letting them burn through the night. This renders the veins soft and brittle. Only on the following day, when the smoke has dissipated somewhat, can the miners enter the mine. With hammer and gad, they dig out the ore.[146]

Chhueh Liang-chhing, who has carefully studied the Yellowstone Pit (*Huang-shih kheng* 黃石坑) of the silver mines at Sui-chhang 遂昌 in southwest Chekiang, a mine that dates back at least to the Sung but which was most extensively mined in the Ming, gives a somewhat more detailed account (unfortunately, without any illustrations or photographs) of firesetting and its results as they can be seen in the remains of that mine:

The miners used brick and rocks to build up a makeshift oven right against the working face, . . . in this way guaranteeing that the full force of the fire would be concentrated against the working face. . . . Because of the limited heat generated by the firewood, the area affected by

[145] Hsia Hsiang-jung *et al.* (*1980*), p. 296.

[146] *Shu Yuan Tsa Chi*, ch. 14, p. 9a. As suggested in this text, firesetting does not have to actually shatter the rock in order to be very useful to miners. Simply by inducing fractures, it could make the use of gad and hammer much easier and more effective. Cf. Barnard (1989), p. 158 for an example at the Ma-yang mines of the Warring States period.

each firesetting was only about 4–5,000 square cm. The fissures generated by the heat reached a depth of 2–5 cm. . . . One can still see clearly a large number of elliptical depressions in the shape of half an egg cut sideways. . . . These depressions came about because of differing temperatures produced in different parts of the wall by the heat of the fire; those parts of the wall opposite the centre of the fire fissured more deeply, those facing the edges of the fire less so. . . . Temperature variations in the firing produced not only these distinctive elliptical shapes but also considerable variation in the size, direction and depth of the elliptoids.[147]

Paul Craddock is not inclined to accept the interpretation that the small areas affected by the firesetting were determined by the intrinsic limitations of the process, especially the heat of the fire. He notes that experiments he has conducted with colleagues show that firesetting can 'easily penetrate 20–30 cm into the face' and remove several tonnes of material at a time. He would argue that, when we find small firesets like this, it was probably because the miners wanted to remove only a small but very specific quantity of rock and/or ore.[148]

Firesetting also served in China as a prospecting and as a beneficiation or concentration technique. Khou Tsung-shih 寇宗奭, writing in the early +12th century just before the fall of the Northern Sung, described the use of firesetting in prospecting at the cinnabar mines of Chin-chou 錦州 which was at that time under the control of the Liao:

The Old Crow Pit (*Lao ya ching* 老鴉井) of Chi-liao thung is several hundred feet wide and deep. Firewood is placed in the pit and set ablaze. This causes the greenstone (*chhing shih* 青石) to split, forming small niches (vugs). In the niches there may appear a bed of jade-like white rock on which the pieces of cinnabar are found.[149]

In beneficiation, or the dressing of ores (see Section (*i*)(1) below), ore that had been heated and quenched was rendered brittle, making it easy to grind in native stone mills.[150]

What is very difficult to determine, not only for earlier periods but for later times too, is how widely Chinese miners resorted to firesetting. Evidence for its use is limited to a small number of literary references, such as that of the *Shu Yuan Tsa Chi* cited above, occasional stone inscriptions,[151] some scattered archaeological evidence[152] as well as some eyewitness accounts from very recent times.[153] In some cases of large-scale

[147] Chhueh Liang-chhing (*1978*), p. 103. Using this technique, the miners at the Yellowstone Pit eventually excavated an area of 70–80,000 cubic m.

[148] Craddock (1992), p. 1. Experiments suggest that smaller fires, at least in some circumstances, make more efficient use of fuel than larger fires; *Ibid.*, p. 5.

[149] *PTKM*, ch. 9, pp. 51–2; de Mély (1896), p. 190. Cf. Vol. 5, pt. 4, p. 241; see also Cibot (1786a), p. 307 which describes the same practice in Shansi 'and elsewhere'. The *Fang Yü Sheng Lan* seems to refer to firesetting during the +13th century at the famous Chen-chou cinnabar mines near present-day Ma-yang in Hunan; Hsia Hsiang-jung *et al.* (*1980*), pp. 313–14.

[150] Read (1907), p. 1297. See also the comments by S. J. Truscott in Holman (1927), pp. 251–3.

[151] E.g. Li Ching-hua (*1981*), p. 79 (Ming (?) gold (?) mines in Chi-yuan, Honan); Tshao Theng-fei & Than Ti-hua (*1985*), p. 120 (Ming iron mining in Kwangtung).

[152] In addition to Chhueh Liang-chhing's report, cf. Hsiung Chhuan-hsin *et al.* (*1985*), p. 122 (Warring States copper mine at Ma-yang in Hunan); An Chih-min & Chhen Tshun-hsi (*1962*), p. 520 (Eastern Han copper mine at Tung-kou, near Yun-chheng, Shansi); Li Ching-hua (*1981*) (Ming gold mines in Chhin-ling, Honan).

[153] E.g. Read (1907), p. 1297 (gold mines in Manchuria); Vol. 3, p. 665 (jade mines in Sinkiang).

mining of recalcitrant ores, such as the iron ores at Li-kuo chien 利國監, we can probably assume with some confidence that firesetting must have been in use.[154] These, however, hardly add up to any kind of overall picture of the extent of firesetting in Chinese mining or any suggestion that it was a commonly used technique.

Indeed, firesetting may have been used less than the effectiveness of the technique might suggest.[155] Certain conditions had to obtain to make firesetting necessary, or desirable, or even possible. Often, they were absent. To begin with, firesetting is a 'prodigal' technique that consumes wood voraciously.[156] A mine of any size would soon use up nearby timber resources, at which point the costs of bringing in wood from farther afield would increasingly undercut the economic viability of the mine.[157] Another possible restraint on the use of firesetting was the wide availability in China of very cheap mining labour hardened to abominable working conditions. Where firesetting was resorted to out of choice rather than out of necessity, it was probably often mainly because of the costly wear and tear on tools when excavating tenacious rock, rather than because of any concern to use labour power more efficiently or to improve the working conditions of the miners.

Specific conditions of individual mines might also restrict the use of firesetting. Firesetting varied considerably in effectiveness depending on the rock being excavated.[158] For example, quartz-rich rocks would probably react much better than shales.[159] Reasonably good ventilation was also necessary if smoke, possibly sulphurous where pyrites or other sulphides were present, was not to render the mine uninhabitable for extended periods after the use of firesetting, or even cause fatal accidents.[160] The smoke problem was compounded in those areas where several mines were being worked in close proximity, since smoke from one mine might filter into neighbouring mines, hindering or preventing work there too.[161] In ores with a high sulphur content, firesetting could set the sulphur on fire. (Hence the word 'pyrites'.)[162] In silver mining, the firesetting process could produce corrosive

[154] Tegengren (1924), p. 237. Even after the invention of dynamite, firesetting continued in use in European mines where the country rock was particularly hard; Timberlake (1990), pp. 49, 50.

[155] The absence of written references to firesetting (or even blasting) in Chhing mines is quite striking. Even Wu Chhi-chün's 'An Illustrated Account of the [Copper and other] Mines and Smelters of Yunnan', the most detailed treatment of Chinese mining technology in traditional times (though limited, of course, mainly to the copper and silver mines of Yunnan), makes no mention of either technique; Wu Chhi-chün (*1845*); Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 628.

[156] Tegengren (1920), p. 10. Bjørn Berg calculates that, in the Kongsberg silver mines in Norway during the latter half of the 19th century, it required 11.3 cubic m of wood to break by firesetting 3 cubic m of solid rock; Berg (1992), pp. 2 and 7, and fig. 2.

[157] The Chinese government sometimes, as in Yunnan in the +18th century, charged officials with the responsibility of encouraging regular planting of rapidly growing trees so as to meet the needs of the mines and smelters; Vogel (1987a), V.2. (Vogel's examples deal with the need for wood for the production of charcoal to be used in smelting the copper ore.)

[158] Fortunately for the miners, firesetting was especially useful in attacking just those hard, recalcitrant rocks that were least able to absorb the stresses induced by differential expansion and the vaporisation of entrapped water; Craddock (1992), p. 1.

[159] Timberlake (1990a), p. 53.

[160] Forbes (1963), p. 202; Healy (1978), p. 85; Timberlake (1990), p. 51; Berg (1992), p. 13; Li Chung-chün (*1982*), p. 2. Recall Lu Jung's comment above (p. 303) that miners had to wait until the next day to enter the mine.

[161] Hoover & Hoover (1912), pp. 118, 120.

[162] Young (1970), p. 61.

vapours from the rocks that in turn destroyed the silver in the ores.[163] Ores containing arsenic could release arsenical fumes, threatening the miners with arsenical poisoning.[164] The heat of the fire could also sometimes alter the ore so as to make it difficult to concentrate.[165] Finally, although skilled miners could control firesetting quite precisely, the technique could become dangerous when employed by less skilled (or less careful) miners. Its use in improper conditions could lead even to collapse of the workings. This problem would be especially serious in just those mines where fractures in the rock would assist in dissipating the smoke from the fires.

(7) Blasting

In Europe, firesetting had long been an established practice by the time the first attempts were made to attack recalcitrant rock with gunpowder. The story of those first efforts in Italy at the end of the +16 century and in the German-speaking mining centres early in the +17 centuries has become much clearer thanks to the recent work of J. Vozar, R. Vergani, Karl-Heinz Ludwig and, in English, Graham Hollister-Short.[166] What is sometimes not sufficiently emphasised is that gunpowder was first used in central European mining only to a very limited degree, largely because of technical problems that had to be solved before it could be used effectively.[167]

Unfortunately, we remain largely in the dark regarding the early uses of gunpowder in mining in China. Given the flourishing state of mining in the Sung dynasty,[168] it might be expected that miners were experimenting with this new technique at least by the +11th century. However, the evidence for its use at that time is very tenuous at best.[169] Even for the succeeding several centuries, we have only very rare indications of blasting as a mining technique. One is the Ling-pao hsien 靈寶縣 gold mining district in the western tip of Honan where the Yellow River makes its sharp bend to begin flowing eastward to the north China plain. Some 800 old pits of varying size have been found here. Many if not most date from the Ming when, according to stone inscriptions, gold mining flourished in this area. In a number of medium size and larger pits (some penetrating 100 or more m into the mountainside), obtuse angle, cone-shaped indentations accompanied by radiating cracks seem to indicate the widespread use of blasting with gunpowder.[170]

[163] Hollister-Short (1985), p. 54. [164] Taylor (1957), p. 25. [165] Young (1970), p. 61.

[166] Vozàr (1978); Vergani (1979); Ludwig (1986); Hollister-Short (1983), (1985). The last is especially good on the considerable inventiveness that had to be applied before the full effectiveness of gunpowder could be realised. Cf. also Vol. 5, pt. 7, pp. 535–8. For a straightforward set of instructions for miners, stressing the need for high quality ingredients and that the miners working with blasting powder should not become overconfident of their skills, see Kern (1779), p. 61.

[167] Molenda (1988), p. 66; Read (1933), p. 244. See also Hollister-Short (1985) and Ludwig (1986). Read properly stresses that imaginative leap required before gunpowder, long familiar in its military applications, could be seen as an aid in mining. After all, the drilling required in order to set the charge was the first example of the use of drilling underground.

[168] Golas (1989); Hartwell (1963), (1966), (1967); Hsia Hsiang-jung *et al.* (*1980*), chap. 5.

[169] Vol 5, pt. 7, pp. 542–3. It is worth noting that, despite a flourishing mining industry in Japan, it may well be that blasting with gunpowder was not used until the second half of the 19th century; Anon. (1909), 23.

[170] Li Ching-hua (*1981*), p. 79. For possibly another Ming use of gunpowder in mining, in this case in Hopeh, cf. Anon (*1978b*), p. 185.

When we look at the more abundant information for the 19th and early 20th centuries, mostly provided by Western observers, it is quite clear that potential advantages of using gunpowder such as the saving on firewood and the ability to continue working immediately after the blast were ordinarily not sufficient to induce Chinese miners to resort to blasting.[171] Nevertheless, the statement (Vol. 5, pt. 7, p. 543) that the use of gunpowder is attested only for quicksilver mining needs revision. Gunpowder was also used in the mining of antimony by native methods,[172] in Szechwan coal mines[173] and in Mongolian silver mines.[174] Even with this paucity of references, their variety strongly suggests that blasting must have played a rôle in many other mines, too.[175]

Some of the reluctance of Chinese miners to use gunpowder probably derived from the disadvantages of gunpowder blasting in the Chinese context.[176] One serious problem was the frequently inferior quality of gunpowder available. As an anonymous author described the situation at quicksilver mines in Kweichow at the beginning of this century: 'The powder used is made at the mine. Owing to the defective mixing of the ingredients of the powder and to the inferior quality of the nitre the explosive force is not very great . . .'.[177] Then there was the cost of shothole-drilling; the danger of igniting fire-damp (methane) in coal mines; the possibility of damage to timbering; the danger of delayed charges when workers, as all too often happened, paid insufficient attention to safety practices.[178] Moreover, where either firesetting or blasting was called for, firesetting was sometimes the preferred technique either because it was more effective than blasting against certain tenacious ores[179] or because the ready availability of timber made it a cheaper technique, or because it required less expertise on the part of the miners, or because it posed a lesser threat of damage to or collapse of the workings.[180] Chinese miners must have faced many

[171] Hollister-Short (1985), p. 50; von Richthofen (1872b), p. 76; Bain (1933), p. 65; Robertson (1916), p. 267; Louis (1891), p. 640.

[172] Cole (1916), p. 370: 'Native-made black powder is used . . .'.

[173] Reid (1901–1902), p. 33. [174] Woo Y. T. (Wu Yang-tsang) (1902), p. 756.

[175] Tegengren, whose opinions must always be taken seriously, says explicitly that '. . . explosives . . . probably were hardly used in China for mining purposes' before the 19th century. Cf. Tegengren (1921), Vol. 2, p. 237. Unfortunately, he does not tell us on what he based this opinion.

[176] Gunpowder was also adopted only with reluctance by European miners in the +16th and +17th centuries. For a discussion of why this was the case, see Ludwig (1982), p. 152 and Ludwig (1986), especially the colourful example describing the injuries suffered in +1642 at Gastein in Salzburg by the blasting master, Obman ain Khnapp, who had a charge spontaneously ignite on him.

[177] Anon. (1907a), p. 152. Hommel describes the gunpowder used by Kiangsi quarrymen in the 1920s as 'ill-triturated and lumpy'. Hommel (1937), p. 10; see also Carlson (1971), p. 46. For a +16th century text on the tedious pounding and grinding necessary to produce good quality gunpowder, see above Vol. 5, pt. 7, pp. 358–9. Even for a high priority use such as weapons, the government found it difficult to assure the quality of gunpowder; Gillan & Cranmer-Byng (1962), p. 301.

[178] Golas (1982); Hollister-Short (1983), p. 112; Ludwig (1986); Berg (1992), p. 4.

[179] Penhallurick (1986), p. 73; Ure (1875), Vol. 3, p. 315; Ludwig (1986), p. 120.

[180] Golas (1982); Tegengren (1920); pp. 17–8; Vol. 5, pt. 7, pp. 543–4; Hollister-Short (1985), p. 42; Mumford (1934), p. 68. Young (1970), p. 187, describes some of the problems that made the ignition of gunpowder so dangerous in early mining in the United States: 'From the employment of gunpowder for the first time in blasting until [the invention of the safety fuse in] 1831, ignition was a chancy and terribly dangerous problem. The military slow match of saltpeter-impregnated cord was not suited for blasting, since it burned entirely too slowly. Miners devised various metal tubes, hollow wooden rods, and even split reeds cleaned of their pith and bound back together with string to contain their igniting composition, all tending either to misfire or fire too quickly.' Firesetting was still in use in the great Rammelsberg mine in the Harz mountains as late as 1878; Shepherd (1980), p. 19.

of the same problems as the miners who first experimented with gunpowder in Italy and Germany.[181]

Lastly, the generally poor quality of ore deposits in China probably discouraged the use of blasting. Thin and irregular deposits especially invite working in a way that attacks only the ore, thus minimising the breaking out and hoisting of waste. Such a procedure becomes even more rational when, as often happens, the ore is relatively friable and easily broken while the country rock encasing it is recalcitrant.[182]

(8) Haulage and Hoisting

Robert P. Multhauf has written: 'The history of the technology of mining, as distinguished from metallurgy, is largely a history of mechanisation, and that mechanisation has until the last century consisted principally in the development of what Agricola calls *tractoriae* – hauling machines.'[183] Multhauf's view of what constitutes 'technology' in mining is obviously rather narrower than ours. Insofar as we try to apply it to hauling activities, it must be noted at the outset that most of Chinese mining saw little more mechanisation in the area of hauling than in other mining activities. The major exception was the windlasses that, at least from the Warring States period, could be found at some, probably relatively larger mines.[184] Indeed, Vogel would argue that it was the very low level of mechanisation of haulage and drainage in Chinese mines that constituted 'one of the most conspicuous differences' between Chinese and European mining.[185] The point seems valid, but only if one contrasts Chinese mining with European mining from the Renaissance onward. For earlier periods, the contrast would be much less marked.[186]

(i) *Minimising haulage*

It is well to remember that, in the typical mining operation, the miners will be excavating not only ore but also a certain amount of waste rock or gangue materials.

181 Vol. 5, pt. 7, p. 535, fn. b; Hollister-Short (1985), *passim.*; Ludwig (1982), p. 152.

182 Young (1970), pp. 81–2. Of course, Chinese miners did not invariably follow this logic. In the cinnabar mines of southeastern Szechwan, gunpowder fabricated by the miners themselves was used at least in recent times on rather poor deposits worked on a very small scale.

183 Multhauf (1959), p. 114. Agricola makes a further distinction between those machines that 'raise not only dry loads, but also wet ones, or water' and those that are used only to draw water, i.e. various kinds of pumps; Hoover & Hoover (1912), pp. 169–70. The same distinction works for the hauling and drainage machines of Chinese mining, though I know of no Chinese author who drew such a distinction.

184 If one includes water pumps as 'hauling machines', they would constitute a second exception, as we shall see below, though also not a very widely used one.

185 Vogel (1991c), p. 76.

186 After establishing that many of the mining innovations attempted even in the +15th and +16th centuries failed, Danuta Molenda (1988, p. 83) argues that the 'main cause of failure lay in the lack of technical expertise and ignorance of the elementary principles of engineering. This was why it frequently happened that machines which functioned well as models failed to work at all when installed in the mines. Too little account was taken of the different geographical, geological and hydrographical factors which might affect the performance of the machinery, so that machines that worked well in one mine proved useless in another or kept breaking down.' Joel Mokyr, for his part, would stress 'the constraints of workmanship and materials' (1990, p. 58). In any case, technical impediments to the introduction of greater mechanisation in mines were, if anything, all the more daunting in China where skilled engineers were even scarcer than in late medieval Europe.

Insofar as the waste materials could be disposed of within the mine rather than by removing them, the need for haulage was reduced. For this reason, the miners frequently practised at least a preliminary process of ore dressing or concentration right at or close to the working face. As far as possible, only pieces of ore would be carried out of the mine. The waste materials would then be disposed of in the easiest and most convenient way, by using them to fill in already worked out areas.[187] Miners were already using this practice in the most extensive mining operations of the Chou period, such as that of Thung-lü shan 銅綠山.[188]

Sometimes, especially where timber was readily available, the miners went to surprising lengths to avoid hauling gangue. At the Sui-chhang 遂昌 silver mine in Chekiang which was worked during the Sung and Ming, miners actually built simple platforms against the walls of the mine. On these platforms, supported by China fir props, they piled up the useless gangue. The platforms, with their loads of rock, were still in place when the mine was discovered in 1966.[189]

(ii) *Carrying or pushing/pulling ore*

Some of the traditional Chinese mines excavated in recent decades have been found to have galleries that are noticeably tall and narrow. Because of this, and because archaeologists have found what appear to be hooks used to suspend baskets from shoulder poles, it has been suggested that this very much easier hauling method was used in these mines.[190] In more recent times, we know that, in the mercury mines of Kweichow for example, miners used shoulder poles and baskets that had a capacity of 40–50 catties, which meant that a full load consisted of some 50–60 kilograms.[191] Moreover, we have a mid-19th century illustration from Yunnan showing haulage of ore using shoulder poles (*thiao-khuang* 挑礦) (Fig. 75), though the scene takes place outside the mine so that it does not tell us that this method of haulage was also used inside the mines.[192] Shoulder poles were also used in the native coal mines of Manchuria at the beginning of this century (Fig. 78) and by Chinese gold miners in Malaysia.[193]

The same Yunnan illustration also shows workers carrying ore in baskets slung over the shoulder and resting on their backs (*pei-khuang* 背礦). These baskets appear to be very similar to baskets with large looping handles that miners in Hopeh used in the same period (Fig. 76).

[187] This could have the further advantage of preventing cave-ins in abandoned areas, with their unpredictable but potentially lethal effects on areas where the miners were still at work.

[188] Vogel (1982), p. 143. [189] Chhueh Liang-chhing (*1978*), p. 104. [190] *Ibid.*; Su Ju-chiang (*1942*), p. 66.

[191] Tegengren (1920), p. 18. Von Richthofen gives another set of figures for the coal mine with steps in the form of a spiral referred to above ((*h*)(3)). It was worked at a depth of 80 m and, though von Richthofen does not say so explicitly, it appears that the haulers used baskets suspended from shoulder poles. According to his calculations, each man would make 20 haulage trips per day, bringing up 25 catties each trip. The 120 men employed in haulage would be able, by his calculations, to bring up some 14,000 tonnes yearly; von Richthofen (1872b), p. 18.

[192] Su Ju-chiang (*1942*), p. 66 reports the use of carrying poles at the open pit mines of Ko-chiu.

[193] Louis (1891), p. 640. A pair of baskets held 'at least 70 lbs.' and could be 'easily carried up steep grades by a Chinese miner'.

Fig. 75. Hauling ore at a 19th century mine in Yunnan. The haulers are 'backing' single baskets (*pei-khuang*) or carrying pairs of baskets slung on shoulder poles (*thiao-khuang*). Wu Chhi-chün (*1845*), Illustrations, p. 5a.

Fig. 76. Chinese miners in Hopeh in the 1860s, photographed by the Scottish photographer John Thomson. Clayre (1985), p. 167. Note the two differently shaped baskets for hauling ore, as well as the mattock, one of the most popular tools of Chinese mining.

Only a small minority of underground mines, however, had walking and working areas large enough for the miners to stand upright.[194] As a result, much of the haulage in Chinese mines was accomplished in the most difficult fashion, by haulers crawling along the ground and pushing or pulling an ore basket to the place where it could be emptied (Fig. 77, (*a*) left and (*b*)).

Alternatively, as at coal mines in Manchuria (Fig. 78) or at the Ko-chiu tin mines (Fig. 79), double baskets or sacks of ore were carried over the shoulder while walking or crawling. In the latter case, the total weight of the load reached as much as 80 or 90 *chin* or not much less than 45 or 50 kg. Haulers were expected to bring up a

[194] This was also a major reason why animals were so little used in Chinese mining though the relative shortage of animals and the extreme cheapness of human labour power may well have been equally or more important.

(a)

(b)

(c)

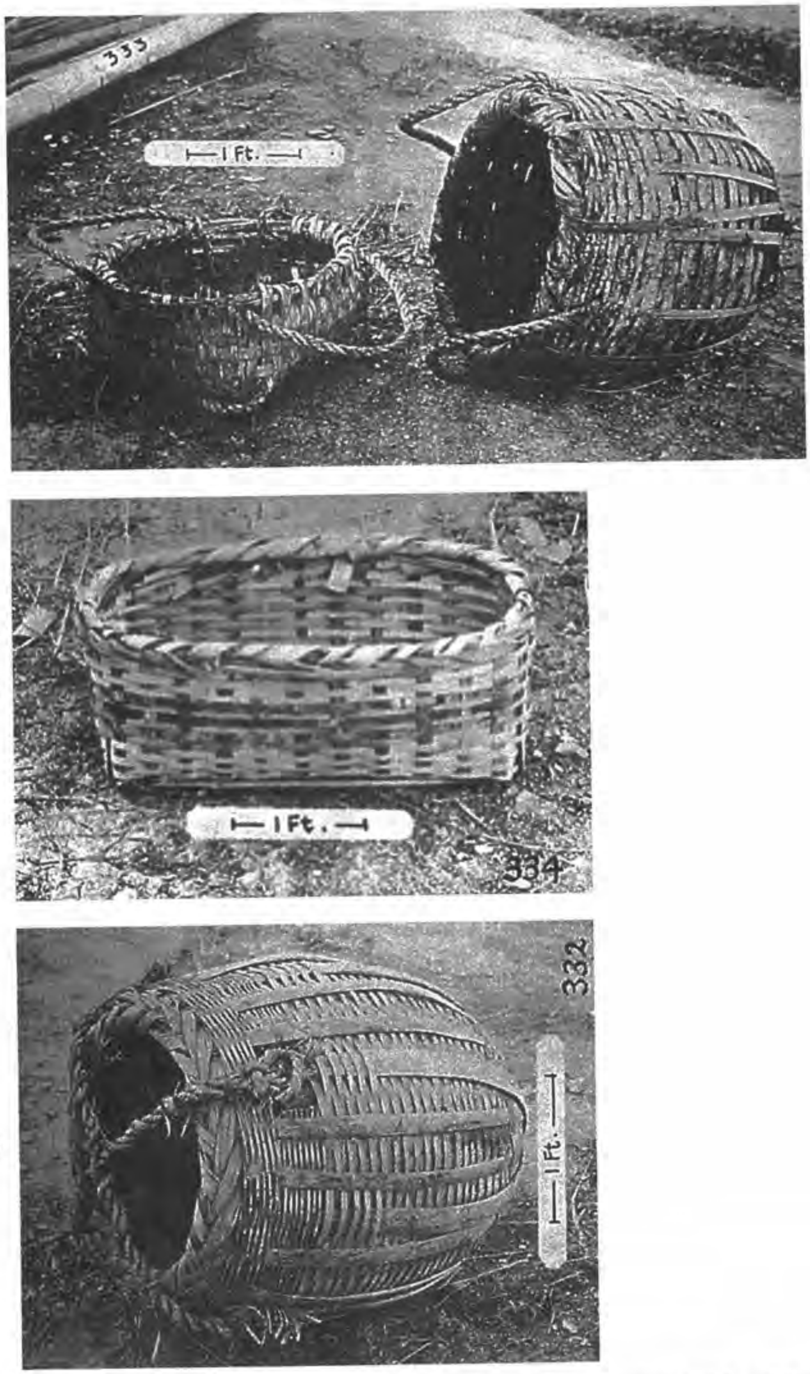


Fig. 77. Bamboo baskets used by coal miners in Kiangsi in the early part of this century: (*a*) left and (*b*) are baskets pushed or pulled along the floor of the mine to either the mouth or to the point where the ore was dumped into the windlass basket (*a*) right. The basket (*c*) was lined with oiled cloth and used to haul water from the mines. Hommel (1937), pp. 4–5, figs. 5–7.

Fig. 78. Miner hauling coal in a pair of baskets in northeast China (Manchuria). Note that, for balance, the front basket is about half the size of the rear basket. Treptow explicitly describes the baskets as being hung from a carrying pole though that is not clear from the photo alone. Treptow (1918), p. 175.

Fig. 79. A double sack made of hemp or leather and used to haul ore inside 19th century mines in Yunnan. Wu Chhi-chün (*1845*), Illustrations, p. 11a.

certain total weight or a certain number of loads each shift, typically something like 500 *chin*.[195] In the copper mines of Yunnan in the 19th century, it typically took four or five haulers to dispose of the ore and gangue excavated by one miner, making the haulers by far the largest segment of the labour force. Theirs was also the most

[195] Su Ju-chiang (*1942*), pp. 66–7. Draper (1931) says the average was 30 kg (67 pounds). At Ko-chiu, a hauler on average could make about 5 trips a day down a 30° incline 650 m long. By contrast, a hauler at a deep Szechwan coal mine early this century 'entered the mine at 8 a.m. with his empty trolley and emerged therefrom at 2 a.m. on the following day, bringing out one load of about 10 cwt of coal as his day's work.' Reid (1901–1902), p. 31.

Fig. 80. A young boy hauling coal in Taiwan at the beginning of this century. Davidson (1903), facing p. 472.

difficult and perhaps most unhealthy work at the mines,[196] but since it required no skill, it was compensated at the lowest possible rates. Often, because of the narrowness of the shafts and galleries, young boys were hired for this work (Fig. 80). At Ko-chiu, the slogan was 'the smaller, the better' (*yueh hsiao yueh hao* 越小越好). Of all the workers in the mines, their working and living conditions were the most dismal.[197]

(iii) *Sledges and carts on rails*

Even in mines where the best of native techniques were in use, sledges drawn by men were often used.[198] Sometimes, ties of wood were laid down to aid the gliding of the sledges (Fig. 81).[199] Small wooden carts with four wooden wheels were also used (Fig. 82)[200] though we cannot yet say when such carts were first used in Chinese mines.[201]

196 Their bodies were repeatedly subjected to rapid changes in temperature as they entered and left the mines; Draper (1931), p. 184.

197 Yen Chung-phing (*1957*), p. 57; Su Ju-chiang (*1942*), pp. 64, 66.

198 Shockley (1904), p. 860. We seem to have no evidence of sledges or carts propelled by winches, as was sometimes seen in European mines; Molenda (1988), p. 66.

199 Junghann (1911), p. 12. Pumpelly (1870, p. 292) mentions 'sleds' being dragged over 'smooth round sticks' in the Chai-thang 齋堂 coal mines to the west of Peking.

200 Andersson (1934), p. 81. The carts (Andersson calls them 'trolleys') used in excavations for 'dragon bones' (i.e., Shang oracle bones) measured 1.3 m in length, 0.6 m in breadth and 0.35 m in height; they were drawn by a crawling man with the hauling rope passing over a shoulder and through his legs.

201 Wheeled haulage carts, sometimes referred to as 'mine dogs' (*chiens de mines*) made their appearance in European mines at least by the late Middle Ages; Braunstein (1983), p. 587.

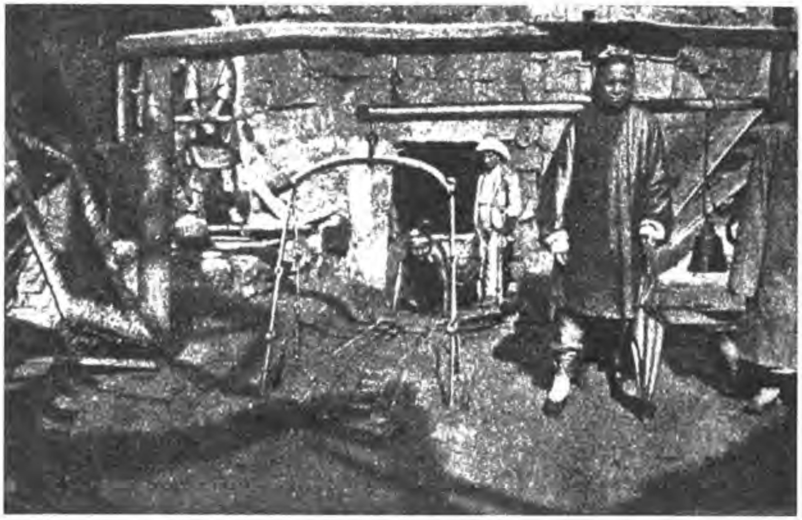


Fig. 81. Entrance to a coal mine in Szechwan with a steelyard arrangement for weighing the coal and wooden tracks for either a cart or sledge. Reid (1901–1902), p. 31. Note the steps between the tracks that provided a foothold for the haulers. (See also *Ibid.* p. 33.)

Fig. 82. Ore haulage cart at a mine in north China, probably Shansi. Erik Nyström archives, Östasiatiska Museet (Museum of Far Eastern Antiquities), Stockholm.

At least by the early 20th century, some Chinese mines hauled ore or coal on small carts running on rails. In the 'baby track railways' found in the mercury mines near Thung-jen 銅仁, Kweichow, bamboo baskets with a capacity of some 60 kg – about what one man could carry in two baskets suspended on a carrying pole – and mounted with wooden wheels were trammed along wooden rails.[202] At least one coal mine in Szechwan had a similar system.[203] Unfortunately, we do not know at this stage whether the use of tracks was an entirely indigenous development or whether knowledge of railroads or even mine tramways in the West might not have been a stimulus. The earlier history of the use rails and carts in mine haulage is just as murky. We have so far turned up no references to the practice in traditional Chinese sources.

(iv) *Hoisting without windlasses*

Hoisting material out of a mine, as opposed to carrying it out, is of particular interest in the early history of mining because it was one area that held out the possibility of substituting mechanisation for brute energy. Hoisting probably began with a basket attached to a rope and one or two men raising the basket by pulling the rope up hand-over-hand. With some kind of waterproofing of the basket, the same method could also serve for drainage. It has been suggested that this was how hoisting was implemented in the early, Western Chou stages of mining at Thung-lü shan. The flat, square baskets found in the excavations could have served this purpose. They would have held about 20–25 *chin* (some 13 kg) of rock, just about what could be hauled up from 20–30 m shafts by one or two men working without mechanical aids.[204] On the other hand, such baskets could also have served for a human-chain kind of hoisting where each basket was passed up from one miner to the next until it reached the surface (Fig. 83).

A great advance occurred when the pulley was introduced. We cannot be sure when that was.[205] However, pulleys would have been so obviously useful that we can only assume that it must have been around the same time (late Warring States or Han) as they began to be used on wells.[206]

For shallow excavations, a well-sweep (counterbalanced bailing bucket) could also have been of use. Very recently, the remains of what have been interpreted to be possibly the remains of a primitive well-sweep were discovered at the Jui-chhang 瑞昌 Thung-ling copper mine.[207]

[202] Tegengren (1920), pp. 13, 18. [203] Wright (1984), pp. 6–7.

[204] Yang Yung-kuang *et al.* (*1980–1981*), p. 85. [205] On the pulley, see above, Vol. 4, pt. 2, pp. 95–6, 266–7.

[206] It is interesting in this context that the most commonly used word for 'shaft' is indeed the word for 'well' (*ching* 井). By the 19th century, pulleys (?) were perhaps used in combination with animal or wind (!) power. Von Richthofen noted this in the Po-shan 博山 coalfields of central Shantung: 'Round shafts 15 ft in diameter, and lined with brickwork, are sunk to a depth of about 240 ft, and the coal is brought to bank in hide skips [baskets], raised by a cable mounted on a pulley and worked by wind-power or cattle. Each skip contains about 400 lb. of coal, and as a full one is raised an empty one is lowered into the shaft.' von Richthofen 1898, p. 444. One wonders if von Richthofen meant a windlass here, especially since Drake (1900, p. 275) describes the raising of coal with a windlass having a drum 1.5 m (5 feet) in circumference and powered by four or five men, but where each basket brought up about 140 kg.

[207] Lu Pen-shan & Liu Shih-chung (*1993*), p. 38.

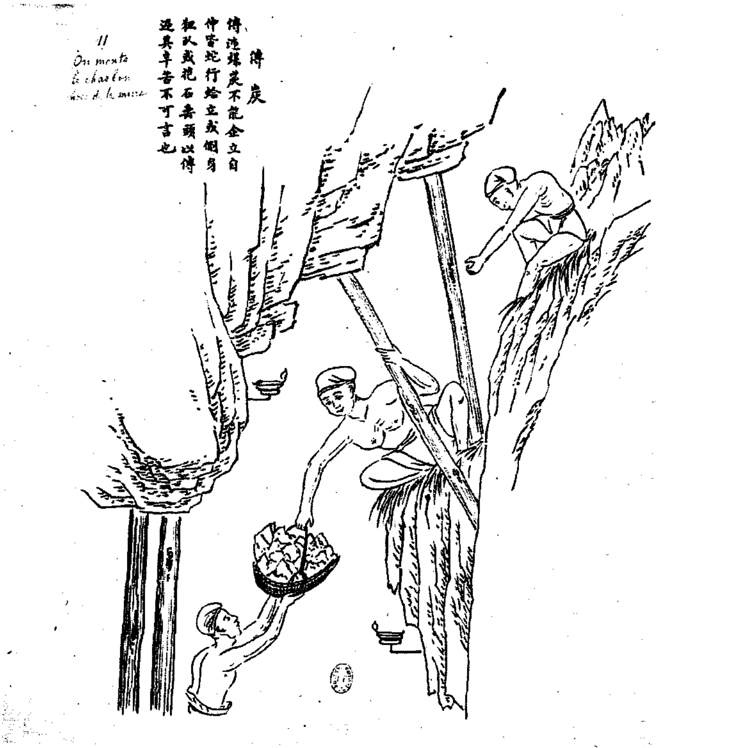
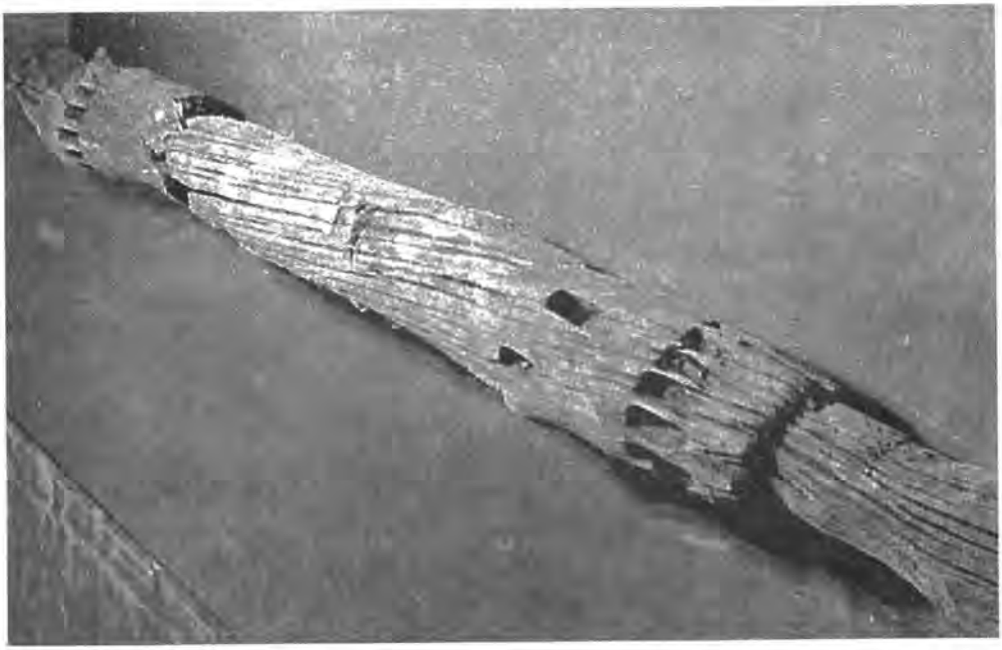


Fig. 83. Miners hoisting coal in a human-chain fashion. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 117, pl. 11.

(v) *Hoisting by means of windlasses*

Among the more remarkable discoveries at Thung-lü shan were two windlass axles.[208] At 2.5 m in length, they could easily have spanned even the largest shaft openings, although this may not have been necessary if, as Barnard suggests, the windlasses were located at the side of the shaft with the rope passing over a pulley or

[208] A number of Chinese scholars have felt that windlasses were used in mining at the latest by the –7th or –6th centuries; see, for example, Liu Shizong *et al.* (1993), p. 62 and Chou Wei-chien *et al.* (*1990*), pp. 20–1. There is now some hard evidence to support that view. Remains of a Shang period wooden windlass are reported to have been found at the Thung-ling copper mine excavations. According to Lu Pen-shan & Liu Shih-chung (*1993*, p. 37): 'The windlass [axle] was formed from a single piece of wood. It is 43 cm long and has a diameter of 42 cm. At each end, there are five evenly-spaced protrusions that could have served as levers for turning the windlass or for restraining [the speed of] the rope.' If this is indeed the remains of a windlass and the dating is sound, it would clearly be the earliest windlass found in China. (The first use of windlasses in mining in the West seems to have occurred in Roman times; Shepherd (1980), p. 20; Coghlan (1956), p. 22.)



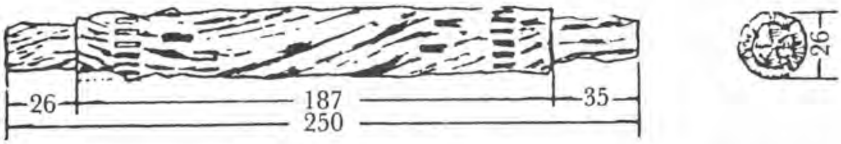


Fig. 84. Wooden windlass axle found at Thung-lü shan 銅綠山, dating from the Warring States to early Han period, 250 cm diameter. At each end, a tongue of 28 or 35 cm has been carved out, presumably to lock the axle firmly between two uprights on which it rested or into which the tongue was fitted. (No identifiable uprights have been discovered.) At either end are two rings of notches. The outer rings, about 45 cm from the ends of the axle, consist of 14 closely spaced rectangular notches about 8 cm long, 3 cm wide and 2–3 cm deep, with 1–2 cm separating the notches. The inner rings are about 25 cm closer to the centre. Each ring has six rectangular notches 8–9 cm long, 3–4 cm wide and 6–8 cm deep, with each notch separated from its neighbours by 8–10 cm. Anon. (1980); Yang Yung-kuang *et al.* (*1980–1981*), p. 86; Vogel (1982), pp. 148, 150; Hsia Nai & Yin Wei-chang (*1982*), p. 7.

similar assembly located directly above the opening.[209] One of the axles, perhaps because something had gone wrong in its construction, had been scrapped before completion and used as a roof support. The other (Fig. 84) presumably served its purpose and survived sufficiently well so as to provide the basis for more than one possible reconstruction.[210] Probably the best version (Fig. 85) was inspired not

[209] Barnard (1989), p. 184, fn. 23. Cf. also Vogel (1982), 147–8; Hsia Nai & Yin Wei-chang (*1982*), pp. 6–8. Since this is about the same period for which we have the earliest evidence for the use of pulleys, it is by no means certain that the use of pulleys preceded the invention of windlasses, as suggested above in Vol. 4, pt. 2, p. 335.

[210] One of the more ingenious was worked out by Noel Barnard in 1981. Barnard (1989), p. 182, fig. 15; reproduced in Penhallurick (1986), p. 42. For a number of reasons, however, it is not very persuasive, and Barnard himself no longer holds to it; Barnard (1989), p. 184.

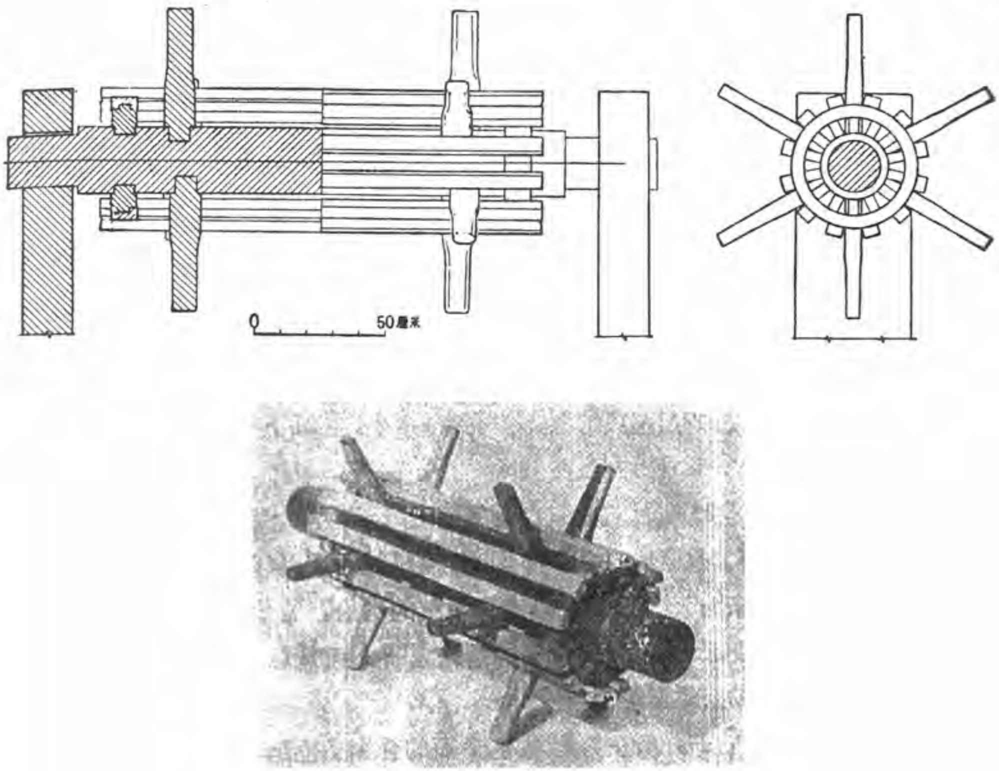


Fig. 85. Reconstruction of the Thung-lü shan 銅綠山 windlass as proposed by Hsia Nai & Yin Wei-chang. (For discussion, see text.) Hsia Nai & Yin Wei-chang (*1982*), p. 7, fig. 8.

only by illustrations of windlasses in the Ming *TKKW* (Fig. 86) but also by those in Agricola's slightly earlier *De Re Metallica*.[211] In this version, the two inner rings of larger and deeper notches are provided with spokes or levers by means of which presumably two miners turned the axle.[212] Into the outer, smaller and shallower notches would be fitted smaller spokes to which would be attached horizontal rods or slats to build up a drum of significantly greater diameter than the original axle

[211] *TKKW*, ch. pp. 316–17; Sun & Sun (1966), pp. 297, 301–2. The drawings reproduced in Sun & Sun are from the original set of illustrations for *TKKW*; the drawings in the Shih-chieh edition of *TKKW* which I have relied on are in this case later versions, and it is interesting that one of these later illustrations of raising and lowering divers from a boat (pp. 312–3) completely omits the windlass that is portrayed in the original as seen in Sun & Sun (p. 297). It is also worth noting that none of these Ming windlasses is portrayed with a crank, even of a primitive kind such as Hommel found used by the coalminers of Kiangsi (Fig. 87). By contrast, some of the windlasses in *De Re Metallica* use cranks (e.g., Hoover & Hoover (1912), pp. 161, 202), others use spokes of the kind proposed in this reconstruction (e.g., *ibid.*, p. 171), and still others use both (e.g., *ibid.*, p. 162), apparently a common practice in +16th century central Europe.

[212] Tu Fa-chhing & Kao Wu-hsun (*1980*, p. 95) suggest the windlass could have been powered when necessary by four men. Because the shaft openings at Thung-lü shan, especially in the Warring States – Han period, were probably larger that the opening of the gem pit pictured in *TKKW* (Fig. 86), it would not have been feasible for the Thung-lü shan miners to apply their pushing or pulling efforts directly to the axle of the windlass as portrayed in Sung Ying-hsing's work.

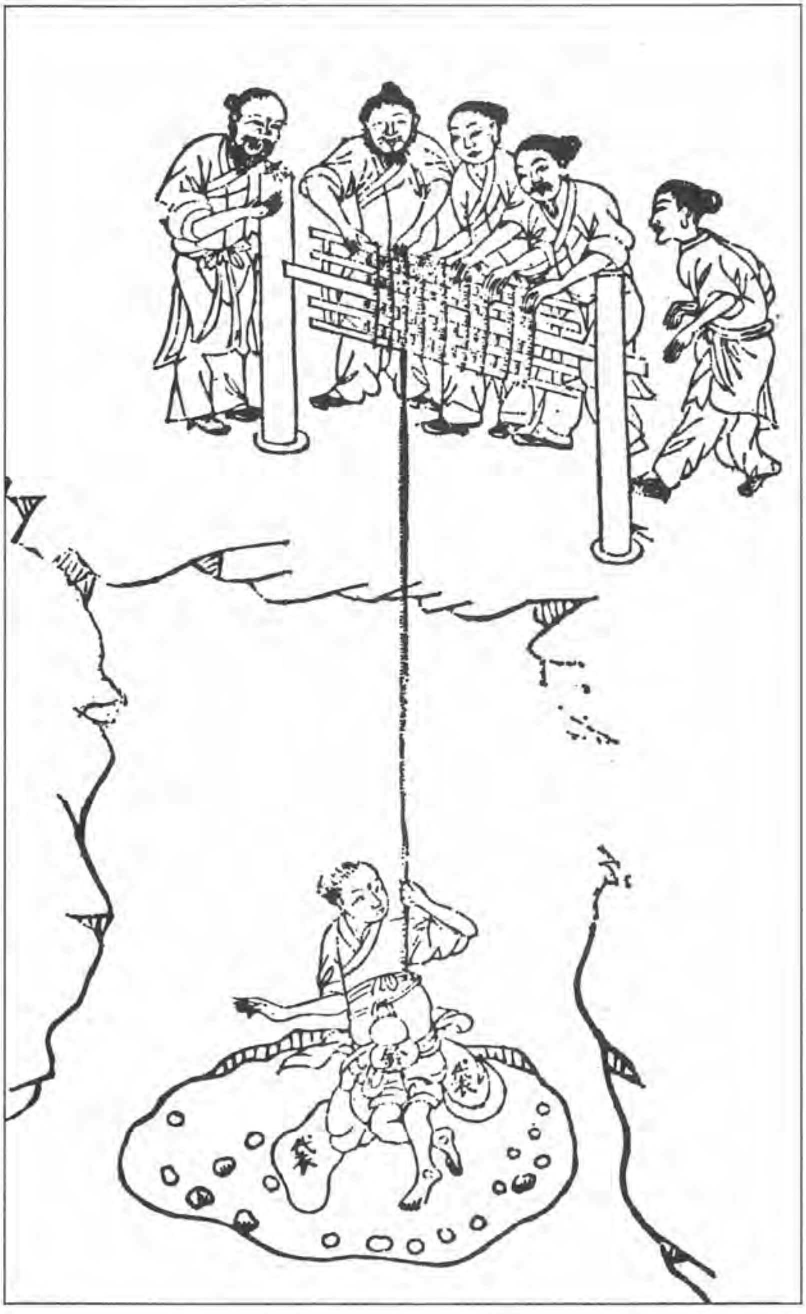
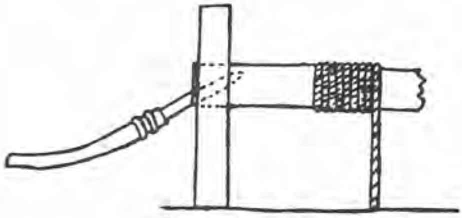


Fig. 86. A Ming gem miner being raised or lowered by means of a windlass turned by three men applying power to the rods or slats forming a kind of drum built up on the axle. Original *Thien Kung Khai Wu* 天工開物 illustration reproduced in Sun & Sun (1966), p. 301, fig. 18–3. The pit or shaft was clearly deeper than suggested here since the author, Sung Ying-hsing, speaks of a 'gem vapour' (*pao-chhi* 寶氣) that regularly attacks miners and can even kill them after prolonged exposure. *TKKW*, ch. 18, p. 306.

(a)



(b)

Fig. 87. Traditional windlasses still in use in this century. (*a*) A sketch of a windlass with a rudimentary crank of the type used by Kiangsi coalminers in the 1920s. A piece of wood is mounted obliquely into the axle, and to this is tied a curved tree branch. (*b*) A photo of a windlass from the same coalfield. (For a general view of this coalfield, see Fig. 1 above.) This windlass is provided with two ropes, one for lowering and one for raising a basket at any given time, the so-called 'balanced hoisting', which could also be accomplished with a single rope. Hommel (1937), pp. 2–3.

but still relatively light. Hsia Nai and Yin Wei-chang reported that a replica built according to this reconstruction with a diameter twice that of the original axle could accommodate twice as much rope as the axle alone and worked twice as fast.[213]

Possibly, as suggested by the Chinese archaeologists, the miners at Thung-lü shan were also already using a system of 'balanced hoisting' whereby the rope of the windlass was coiled about its axle in such a way that the weight of a descending

[213] Hsia Nai & Yin Wei-chang (*1982*), p. 8. It had earlier been proposed that the outside notches had been used in some kind of braking system (*chih tung chia* 制動閘, 'damper brake') but that seems improbable not only because no one could come up with a persuasive suggestion of how the braking would have worked but also because it does not appear that there would have been any need for a special braking device; *ibid.*, p. 7; Yang Yung-kuang *et al.* (*1980–1981*), pp. 85–6.

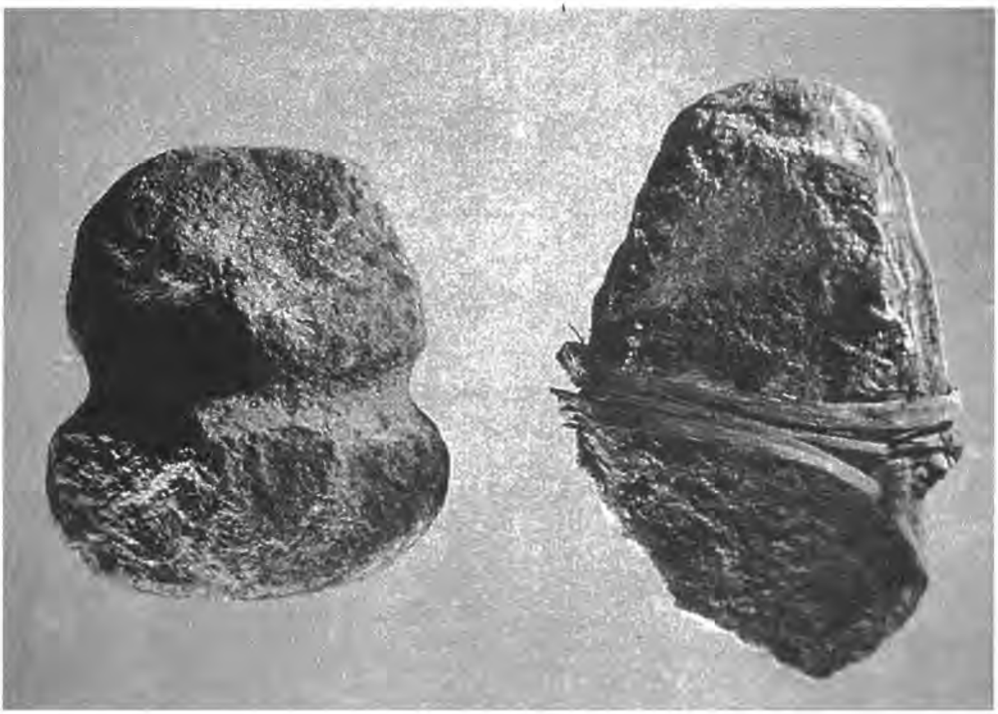


Fig. 88. Grooved stones found at Thung-lü shan 銅綠山 that have been interpreted by Chinese archaeologists as having served as windlass counterweights, as illustrated in Fig. 102, for lifting water. Anon. (1980), n.p. If the well windlass illustration in the *Thien Kung Khai Wu* 天工開物 is to be believed (though its clumsiness gives rise to doubts), such counterweights could also be used in quite different fashion on crank-powered windlasses. Sun & Sun (1966), p. 25, fig. 1–14; Vol. 4, pt. 2, p. 336, fig. 574.

empty basket or even a stone used as a deadweight would make it easier to haul up a basket with its contents (Fig. 88 and Fig. 89).[214]

Even with the best available windlass design and construction, a single windlass and shaft could not handle haulage from the deeper Thung-lü shan workings.[215] The miners may have begun solving this problem as early as the Spring and Autumn period as the 'blind shafts' we described above evolved into single shafts divided into stages, each equipped with its own windlass (Fig. 89).[216]

Apart from the illustrations in *TKKW*, information on the use of windlasses in Chinese mines from the later Han to the 19th century is practically non-existent. One would like very much to know if there were any improvements in windlass construction such as the windlass equipped with a flywheel that Agricola

[214] Hsia Nai & Yin Wei-chang (*1982*), p. 8. Alternatively, two ropes coiled in opposite directions could have been used; Barnard (1989), p. 181.

[215] Thung-lü shan miners worked as deep as 50 m and more below the surface (Table 13) while, even in the early 20th century, haulage stages in native mines were commonly only about 20 m in depth; Junghann (1911), p. 13. In many cases, this must have been the practical limit of windlass hoisting, though Braunstein (1983, p. 584) says 15 m. But Tu Fa-chhing and Kao Wu-hsun (*1980*), with seemingly no evidence apart from the diameter of the drum, claim that these windlasses could have hoisted water or solid matter from depths of more than 50 m.

[216] Yang Yung-kuang *et al.* (*1980–1981*), p. 85.

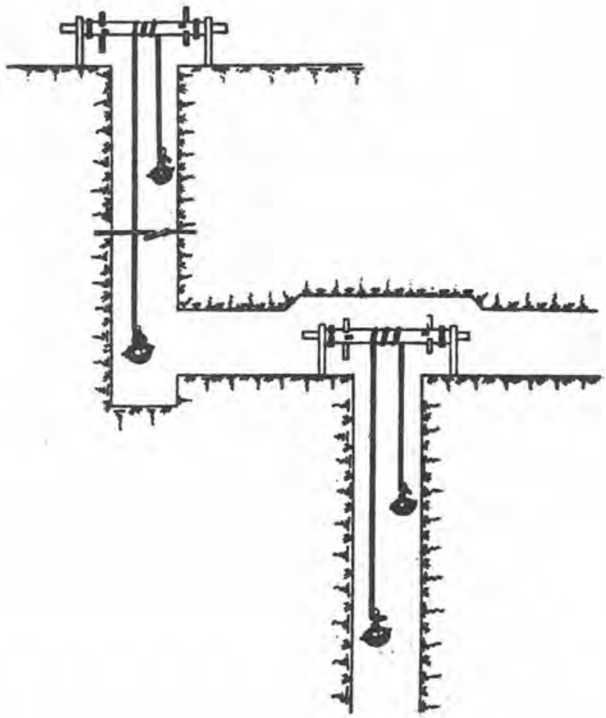


Fig. 89. Hoisting in stages as it may have been implemented at Thung-lü shan 銅綠山 during the Warring States–Han period. Anon. (1980), n.p.

describes.[217] We also lack information on the use of animals to power windlasses. This must have occurred from time to time at the pithead though few Chinese mines were spacious enough to make it feasible underground.[218] Besides, there was all that cheap human labour available, leading to another interesting contrast between Europe and China. In the central European mines described by Agricola, windlasses seem most often to have been turned by '[t]wo robust men'.[219] In China, however, the little evidence we have suggests that windlasses were seldom worked by as few as two men. The windlass at the gem pit in *TKKW* is manned by five men, three of whom are actually working it.[220] Junghann suggests that the most commonly used windlass in Chinese mines early in this century was manned by three men on each side and typically brought up something under 100 kgs.[221] Larger windlasses in the Shansi coal fields, about 1.5 m in circumference and manned by four or five men on each side, could hoist about 135 kg of coal.[222]

[217] Hoover & Hoover (1912), p. 162. Other possible areas of improvement would have been the construction and size of the containers, the kinds of cables, chains or pulleys used, and the overall size and strength of the windlasses; Molenda (1988), pp. 66–7.

[218] We have at least one instance from Shantung early in this century where horses powered a windlass; Junghann (1911), p. 13.

[219] Hoover & Hoover (1912), pp. 160–1; 171. [220] Sun & Sun (1966), p. 301. [221] Junghann (1911), p. 13.

[222] Drake (1900), p. 275; Jameson (1898), p. 366. The largest windlasses found at Chinese mines might hoist as much as 225+ kg; Junghann (1911), p. 13. This seems also to have been the norm at the Almaden mercury mines in Spain; de Betancourt (1990), pp. 32–3.

Fig. 90. Overhead tramway used at a coal mine on the upper Yangtze in the mid-19th century. From Blakiston (1862), as reproduced in Williams (1883), Vol. 1, facing p. 306. Robertson (1916, p. 270) notes that 'Where there are ledges of any width below the mines they have to operate the cable-ways in sections, as the sag is so great that the baskets could not clear the ledges.'

(vi) *Aerial tramways*

Where conditions were particularly favourable, the Chinese sometimes used an aerial tramway to transport product from the mouth of the mine. Thomas Blakiston described one of these aerial tramways used at a coal mine on the upper Yangtze in Szechwan (Fig. 90): '. . . thick hawsers, made of plaited bamboo, are tightly stretched from the mouth, or near the mouth, of the working gallery, to a space near the water where the coal can be deposited. These ropes are in pairs, and large pannier-shaped baskets are made to traverse on them, a rope passing from one over a large wheel at the upper landing and down again to the other, so that the full basket going down pulls the empty one up, the velocity being regulated by a kind of break [*sic*] on the wheel at the top.'[223] S. Wells Williams, after citing this passage, makes the comment, applicable to so much of the native practice in Chinese mining: 'With such

[223] Blakiston (1862), p. 265. Robertson (1916, p. 270) adds some important details: 'The track cables are plaited of flat strips of bamboo (much like the towing ropes used by the boatmen) and are about 4 inches in diameter. At the lower terminal, provision is made for taking up the slack by taking a hitch on the track cable with a smaller rope, also of bamboo, which passes around a roller log. This log is turned by capstan bars and blocked when the desired tension is obtained. [For an example of this same technique applied to a frame- or bow-saw, cf. Vol. 4, pt. 2, p. 54, Fig. 362.] The haulage rope is 0.75 in. diameter, also of bamboo, but twisted in three strands. One end of it is attached to a bamboo basket on each of the track cables. At the upper terminal it makes several turns round a vertical drum and the speed is controlled by other bamboo ropes acting as friction brakes on this drum. . . . This pair of ropes is said to cost 40,000 cash . . . and lasts one year.'

inexpensive methods of getting coal to the water-courses, foreign machinery can hardly be expected to reduce its price very materially.'[224]

(9) Lighting

In western Asia and Europe, mine lighting typically progressed from the use of torches of various kinds to the use of lamps.[225] What little evidence we have for Chinese mines, together with some reflection on the limited options open to the miners, suggests the same general development took place in Chinese mining. One tantalising bit of evidence, from Thung-lü shan, is the lengths of bamboo found to show traces of burning on one end. Chinese scholars have not been able to agree that these were indeed torches for lighting. Those who reject that interpretation argue that the oxygen conditions in the Thung-lü shan mines would have made the use of torches for lighting highly unlikely. Hans Ulrich Vogel, on the other hand, has come up with the reasonable suggestion that such bamboo torches may have been used only occasionally, when necessary.[226]

This reminds us that much traditional Chinese mining – we cannot say just how much – was actually accomplished in the dark, as it were. We know, for example, that +13th century miners excavating the rocks that would provide the raw material for the famous Tuan-chhi 端溪 inkstones worked in complete darkness. They selected the stones by feel but did not know whether they were truly good until they examined them in daylight.[227] We shall return to this question shortly when we note that lack of oxygen sometimes left miners with no option but to work in darkness.[228]

In recent centuries, and probably earlier too, most of the lighting in Chinese mines was provided by oil lamps (Fig. 91). In the Yunnan copper mines during the Chhing, where typically one lamp holding one-half a *chin* (about 300 grams) of oil provided lighting for four or five miners, the two major expenses in mining were food for the miners and oil for the lamps, with the cost of oil running at as much as half the cost of food.[229] Economic considerations thus strongly encouraged holding lighting costs to an absolute minimum.

Oil lamps were so widely used in Chinese mining because they met well the needs of the miners. They were simple, relatively inexpensive and dependable. Even when electric lamps became available, miners frequently continued to prefer the old oil lamps. They found the electric lamps too heavy and clumsy, and unable to provide as good light as oil. Moreover, the electric lamps were costly and had to be recharged after every 24 hours of use. At the Ko-chiu tin mines, recharging required a trip to the town of Ko-chiu, which might be several hours away from the mine. Finally,

[224] Williams (1883), Vol. 1, p. 306. [225] Bromehead (1954), p. 566.

[226] Vogel (1982), p. 143. [227] *Yü Thang Chia Hua*, ch. 5, pp. 3a–b.

[228] Bad or no lighting can afflict miners with a disease called nystagmus ('stag's eye') which not only can produce partial or even total blindness but also, because it represents a nervous condition, can lead to mining accidents; Shepherd (1993), p. 40. I have not seen any references in traditional texts to this disease though it must have afflicted Chinese miners too.

[229] Yen Chung-phing (*1957*), pp. 58–9.

(a)

(b)

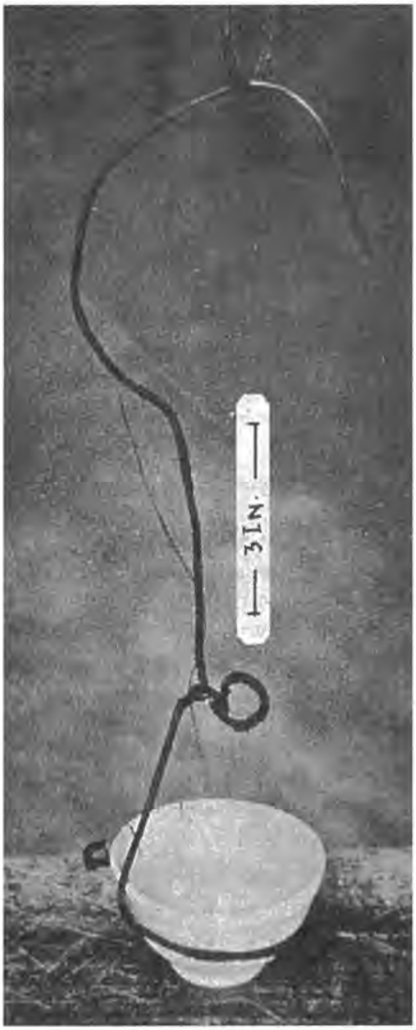


Fig. 91. The 'standard' Chinese miner's lamp of recent centuries. A version (*a*) used by copper miners in Yunnan in the mid-19th century (Wu Chhi-chün (*1845*), Illustrations, p. 11a) and another (*b*) used by coal miners in Kiangsi early in this century (Hommel (1937), p. 3). The bowl could be refilled during the shift with vegetable oil the miner carried in a bamboo container.

a very practical consideration at least for the miners at Ko-chiu, oil lamps could do double duty in the evening for lighting opium pipes, saving the miners the expense of costly opium lamps that were also difficult to protect against thieves.[230]

The main case where non-economic conditions precluded the use of oil lamps was in those coal mines plagued by methane gases and where the use of any kind of flame ran the risk of triggering an explosion. At least by the end of the +16th

[230] Jarland (1921), 347, 374–5; Anon. (1926), p. 154.

Fig. 92. A +16th century Chinese coal miner working by the light of two lamps with enclosed flames. *PTKM*, *thu chüan shang* 圖卷上, 11a.

century, Chinese coal miners attempted to mitigate this risk by using lamps in which the flame was enclosed (Fig. 92). Chinese miners also found workable alternatives in rotton wood or resins (perhaps mixed with sawdust) that burned without a flame,[231] though we do not know how early these were used.

[231] Huc (1859), p. 190; Hommel (1937), p. 4.

(10) Ventilation

For the considerable amount of Chinese mining carried on at relatively shallow depths, ventilation posed no serious problems.[232] Though fetid, the air provided by natural ventilation usually contained at shallow depths at least sufficient oxygen to enable the miners to keep working. Breathing foul air was simply another misery of work as a miner. In the worst of conditions, miners continued to work in the dark because of insufficient oxygen to keep the flames in their lamps lit.[233] This phenomenon is not as unlikely as it might seem. Air at the surface of the earth contains 21 per cent oxygen by volume. Life may be just barely sustained with 10 per cent oxygen in the air, but breathing becomes laboured for a man at work if oxygen drops down to about the 15 per cent level. On the other hand, a minimum of 17 per cent oxygen is required to keep an oil or candle flame burning.[234] Thus the oxygen level in these mines must have been around 15–17 per cent. Throughout Chinese history, such conditions probably have occurred in many small mines even though they failed to draw the attention of the writers of memorials or books.[235]

As mines became larger and excavation proceeded ever deeper,[236] ventilation became an increasingly acute problem. Even if lack of oxygen did not entirely preclude mining, as it did for example in many coal mines in Yunnan,[237] it might force seasonal work stoppages. In Manchurian coal fields early in this century, miners worked only from September to June, partly because of the lack of ventilation in the hot summer months.[238] The problem was compounded especially in metal mines by the miners' frequent practice of following closely the twists and turns of orebodies in order to avoid as far as possible unnecessary excavation. The resulting narrow, winding workings minimised the effects of natural ventilation, decreasing even further the limited supply of oxygen.[239]

Besides the lack of oxygen, the possible presence of carbon dioxide was a further threat to miners. Carbon dioxide is a product of complete combustion and can be created by respiration (exhaled breath contains 4 per cent carbon dioxide), the flames of lamps, the rotting of timbers and the oxidation of coal and coal dust. It can also enter the mine in emanations from the rocks or by escaping from certain mineral waters.[240] Three per cent carbon dioxide causes breathing to become difficult while

[232] Even into this century, smaller Chinese coal mines typically relied on natural ventilation; Wright (1984), p. 39. For general discussions of ventilation in mining, see Stoces (1958), Vol. 1, Chap. XX and Lewis (1964), chap. XX.

[233] Collins (1909–1910), p. 2. This was hardly a problem unique to China. In the early 19th century, candles barely stayed lit in the foul atmosphere of Cornwall tin mines; Morrison (1992), p. 14.

[234] Stoces (1958), Vol. 1, pp. 519–20; Lewis (1964), p. 694.

[235] One scholar has put the loss of life from anaemia in the −5th century Laurion mines at 12 to 14% of the labour force per year; Shepherd (1993), p. 89.

[236] Recall the depths presented in Table 14. [237] Brown (1923), p. 79.

[238] Moller (1902–1903), p. 139. [239] Slessor (1927), p. 61.

[240] Stoces (1958), Vol. 1, pp. 520–1. In the case of sulphide ores, highly noxious sulphur dioxide gas could result from the oxidation of sulphur as it reacted with air and dampness; Checkland (1967), p. 46.

suffocation and death occur at 18 per cent. Since this gas is odourless, special measures are needed for its detection.[241]

By the Sung at the latest, Chinese miners were taking at least simple precautions against dangerous gases. As Khung Phing-chung 孔平仲 (2nd half of the +11th century) describes one of them:

At Tshen-shui chhang 岑水場, Shao-chou 韶州 [present-day Shao-kuan 韶關 in Kwangtung], copper was discovered some years back at a depth of something over 60 m. Now, because of the progressive exhaustion of the copper, [the miners] are forced to go as deep as 250 and more metres. The miners say there are many evil apparitions underground. If they encounter 'cold smoke vapours' [*leng yen chhi* 冷烟氣, probably carbon dioxide], the miners can die. Therefore, when they first enter an excavation, the miners have to test the air using a long bamboo tube with a flame at the end. If the flame turns blue-greenish, this is a sign of cold smoke vapours. They then withdraw in all haste without going any farther, and avoid that excavation in the future.[242]

In coal mines, ventilation was of special concern because of the potential presence of methane or marsh gas which might explode without warning.[243] Interestingly, *bad* ventilation was sometimes a protection against the explosion of methane gas. Methane must combine with oxygen to form an explosive mixture (firedamp) and, since poor ventilation meant much less circulation of oxygen to combine with the methane, the likelihood of explosions was much diminished. Moreover, when explosions did occur, they were likely to be far less powerful.[244] Thus, Sung coalminers knew that, if an explosion occurred, they should hurl themselves face down (*chi i mien ho ti* 亟以面合地), making it possible for the fire to pass over them without causing serious injury.[245] This technique was used in recent times in the West to prevent unexpected explosions. A miner who wore only the protection of a well-moistened coat and a mask with glass lenses crawled into the working holding out a stick with a candle on it in order to set off the methane gas before the rest of the miners entered.[246]

Chinese miners at least by the Ming were also aware that newly opened coal was especially likely to liberate dangerous quantities of gas.[247] There is an interesting illustration in *TKKW* showing a long bamboo pipe let down into a coal pit to draw off noxious fumes (Fig. 93). Tim Wright comments that the 'illustration suggests that this method was primarily useful in small bell-type pits'.[248] But Sung Ying-hsing's description does not seem to fit that interpretation very well. Sung writes:

[241] Lewis (1964), p. 694. Carbon monoxide, a product of incomplete combustion, is extremely poisonous. It rarely occurs naturally in mines, however, though it can be a special danger after an explosion. 'Miners unharmed by an explosion have attempted to walk out of the mine, only to be overcome by the carbon monoxide, which may persist in a fatal quantity in the mine atmosphere for some time after the explosion.' *Ibid.*, p. 697.

[242] *Than Yuan*, ch. 1, cited in Chhi Hsia (*1987–1988*), vol. 2, p. 546; Yang Wen-heng (*1978*), p. 307. There is some question whether the *Than Yuan* was actually written by Khung; cf. Miyashita (*1967*), p. 154, n. 40.

[243] Freshly exposed coal can rapidly liberate a great deal of methane; Lewis (1964), p. 695.

[244] Rushmore (1912), p. 314. Concentrations of methane between 5 and 14% are explosive; Lewis (1964), p. 695.

[245] Chhi Hsia (*1987–1988*), vol. 2, p. 547, citing *Than Yuan*, ch. 1.

[246] Rushmore (1912), p. 314.

[247] Lewis (1964), p. 695. The high levels tend to decline fairly rapidly.

[248] Wright (1984), p. 7.

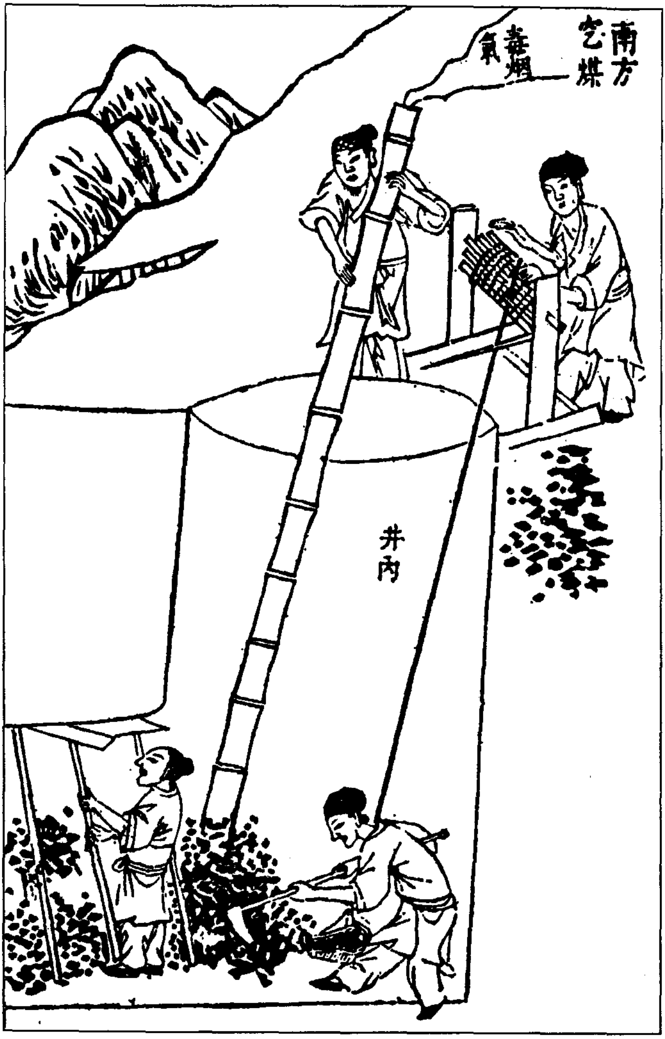


Fig. 93. Venting poison gases from a coal mine in south China. Sun & Sun (1966), p. 204; compare with *TKKW*, ch. 11, p. 209.

Coal can [generally] be obtained only by excavating to a depth of five *chang* (about 15 m). When the coal seam first appears, a poisonous gas burns [the lungs] of the miners (*tu chhi cho jen* 毒氣灼人). Sometimes, a gigantic bamboo trunk with its nodes hollowed out and one end shaped into a sharp point is thrust into the coal seam, allowing the gas to escape upward through the bamboo. The miners can then use their mattocks to excavate the coal underneath. Sometimes, from one main shaft, the coal radiates out in several directions. In that case, the miners follow the seams in their excavations, supporting the roofs of the galleries with timbers in order to prevent their collapse.[249]

In most cases, good general ventilation was probably the best protection against methane explosions. As E. H. Parker wrote in 1904, describing the coal mines of Hupeh and Szechwan: '. . . the coolies wore ordinary oil-lamps made fast round their foreheads.[250] The foremen, who seem to understand something of the principle of fire-damp, said that these lamps were perfectly safe so long as the ventilators were kept active.'[251] Actually, the lamps themselves, in addition to serving as a rough indicator of the amount of oxygen in the air, could also serve as warning devices for methane since a burning halo of gas appears above the flame when methane is present.[252]

Good ventilation could also help preserve the timbering of mines and cut down the incidence of pulmonary diseases such as silicosis. Long experience must have taught some miners that timbers tended to hold up better in well-ventilated mines but there seems to be no trace of this recognition in the surviving records.[253] Silicosis, on the other hand, was much easier to recognise. As Khung Phing-chung 孔平仲 noted: 'Rockdust injures the lungs of those who gather rocks in the Chia-ku 賈谷 hills; many of them die from dried-out lungs.'[254] It is highly unlikely, however, that concern for miners' long-term health ever had much influence for the provision of better ventilation in the mines.

The three major means used by Chinese miners to improve ventilation were the differential pressure method, the 'furnace' method, and airpumps.

Already at Thung-lü shan 銅綠山 during the Warring States period, Chinese miners used the differential pressure created by sinking shafts from different levels

[249] *TKKW* 11, p. 202. My translation. Compare Sun & Sun (1966), p. 205; Anon. (1983), pp. 268–9; Yabu'uchi (*1969*), p. 220. What Sung seems to be saying and illustrating is that, given the danger of the release of poisonous methane gas especially when the coal seam is first breached, this method will lessen the danger regardless of how large the mine may eventually become.

[250] Presumably what we see with the two men on the right in Fig. 82.

[251] Parker (1904), p. 258. Hommel, writing around 1937 about the coal mine at 'Kong Tong' village in Kiangsi where the coal seams were 30–50 m below the surface, notes that: 'When coal is reached the seam is taken out, but not much lateral digging is done on account of the danger of inflammable gases, against which the Chinese do not know how to protect themselves.' Hommel (1937), pp. 3–4. Whatever the situation in these Kiangsi mines, Hommel has clearly overgeneralised here.

[252] Stoćes (1958), Vol. 1, p. 525. This was an advantage that oil lamps and oil safety lamps had over the electric lamps that replaced them. Oil lamps would also be somewhat less dangerous than one might think because there is a time lag before a flame ignites methane. Thus, in mid-19th century coal mines west of Peking, the gas from the coal regularly extinguished the flame of the lamps without igniting; Edkins (1867), p. 246.

[253] Ure (1875), Vol. 3, p. 307; Godoy (1990), p. 54. Actually, it was sometimes better if the ventilation was not *too* effective. A certain amount of dampness in a mine can help preserve timbers, keeping them from drying out, rotting and breaking; Godoy (1990), p. 143.

[254] *Than Yuan*, ch. 2, cited in Miyashita (*1967*), p. 150. Trans. Elvin (1973), p. 187, modified.

to produce a natural airflow.[255] The flow was sometimes further aided by smoothing the walls of the mine with kaolin mixed with straw or by lining them with thin strips of wood or bamboo.[256] The air could also be more efficiently directed toward the working face by walling off part of a shaft or gallery to form an air duct,[257] or by filling in or closing off worked-out drifts, as was also done already at Jui-chhang 瑞昌 and at Thung-lü shan 銅綠山.[258] Despite all of these measures, however, the differential pressure method clearly worked better in the atmospheric conditions of autumn and winter; many Chinese coal mines in particular had to close in the summer because of insufficient atmospheric pressure.[259]

Separate ventilation shafts were much used in Chinese mining throughout the traditional period.[260] Airflow, however, was sometimes a problem, especially in those seasons when there was little air movement at the surface. In these cases, the draught might be assisted by lighting fires at the bottom of the exit shaft in order to create an updraft, the so-called 'furnace' method (Fig. 94).[261]

The 'furnace' method had a number of disadvantages, not the least of which was the danger the smoke created for ascending and descending miners.[262] Alternatively, fans could be used to circulate air (Fig. 95). This method was not much used by Chinese miners, however, probably because of its inefficiency.[263] In those rare operations where fan-powered ventilation was to be found, the fans were normally of the same type as in the enclosed rotary fan winnowing machines ubiquitous in Chinese agriculture.[264] The effectiveness of the fans was sometimes increased by the use of air ducts. There is an illustration of this kind of installation in the *Tien-nan Khuang-Chhang Thu Lueh* (滇南礦廠圖略) of Wu Chhi-chün 吳其濬 which,

255 Anon. (1983), p. 265; Yang Yung-kuang *et al.* (*1980–1981*), pp. 85–6. Typically, the main hoisting shaft served as the outlet shaft for ventilation since it would have the strongest uplifting stack draft (Young (1970), p. 175) but temperature conditions sometimes led to a reversal of the air flow; cf. Stočes (1958), Vol. 1, pp. 526–7.

256 The spaces between the strips might be filled with kaolin; Vogel (1982), p. 143. Straw continued as a popular liner for mine walls. In the late 19th century, at the Thung-shan (Kaiping mines), 'The shaft is lined with native straw to a thickness of 12 in. all around, the straw being plaited into ropes 4 in. thick.' Anon. (1897a), p. 117.

257 Lü Tai-ming (*1986*), p. 201 (Ta-thung coal mines). Various materials were used for this purpose: cloth, reed mats, wooden planks and bamboo; *Ibid.*

258 Lu Pen-shan & Liu Shih-chung (*1993*), p. 37; Anon. (1983), p. 265; Hsia Nai & Yin Wei-chang (*1982*), pp. 5–6. Unfortunately, it is impossible to determine when early miners first understood that this practice improved ventilation. When one encounters in excavations of early mines evidence of filled-in drifts, the first assumption must be that it was done to minimise haulage to the surface. Only when there is evidence that an area has been intentionally sealed off can we fairly confidently hypothesise that this was done to improve ventilation.

259 Lü Tai-ming (*1986*), p. 202.

260 The earliest textual reference to separate ventilation shafts and galleries seems to be in Sun Yen-chhüan's +1666 *Yen Shan Tsa Chi*; cited in Lü Tai-ming (*1986*), p. 201. For other examples, see Su Ju-chiang (*1942*), p. 30 (Ko-chiu tin mines); Woo Y. T. (Wu Yang-tsang) (1902), p. 755 (silver mines in Mongolia); Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 677 (coal mines in Shantung); Edkins (1867), p. 246 and Pumpelly (1870), p. 292 (coal mines west of Peking).

261 Yang Yung-kuang *et al.* (*1980–1981*), p. 86 (Thung-lü shan); Chhueh Liang-chhing (*1978*), p. 104 (the Yellowstone Pit silver mine in Chekiang, worked from the Sung to the Ming); Shockley (1904), p. 860 (describing well run native coal mines at Ta-yang, some 15 km east of Lin-fen 臨汾 in Shansi). The furnace method may have been discovered accidentally through the use of firesetting which can assist ventilation since the less dense warmer air will tend to rise, thereby creating an air flow.

262 Edkins (1867), p. 246.

263 Kovanko (1838), pp. 208–9. (I am indebted to Donald B. Wagner for drawing my attention to this article and providing me with a copy.)

264 Wu Chhi-chün (*1845*), ch. 1, p. 4a; Pumpelly (1870), p. 292. For discussion of these winnowing machines, with illustrations, cf. Vol. 4, pt. 2, pp. 151ff.; Vol. 6, pt. 2, pp. 366ff. and Temple (1987), pp. 23–5.

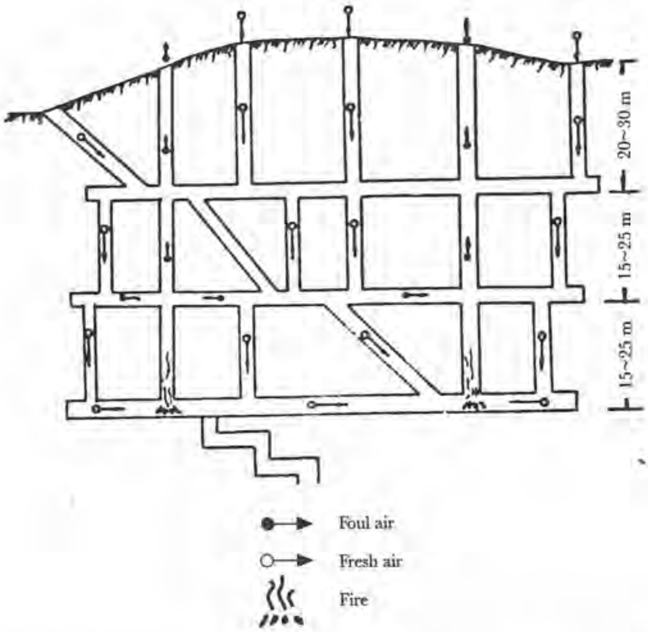


Fig. 94. A schematic drawing showing air flows that the furnace method might have produced at Thung-lü shan 銅綠山, with its multitude of shafts and short galleries. Yang Yung-kuang *et al.* (*1980–1981*), pp. 85–6. The evidence for the use of this method at Thung-lü shan is less conclusive than one would like, consisting of short bamboo sticks, some of them showing signs of having been burnt, that were found during the excavations. One cannot be certain, however, that these sticks were not used for illumination, as discussed above (see (*h*)(9)). Hsia Nai & Yin Wei-chang (*1982*), p. 8. (This point is missed in Hsia Nai & Yin Wei-chang (1982), p. 39.)

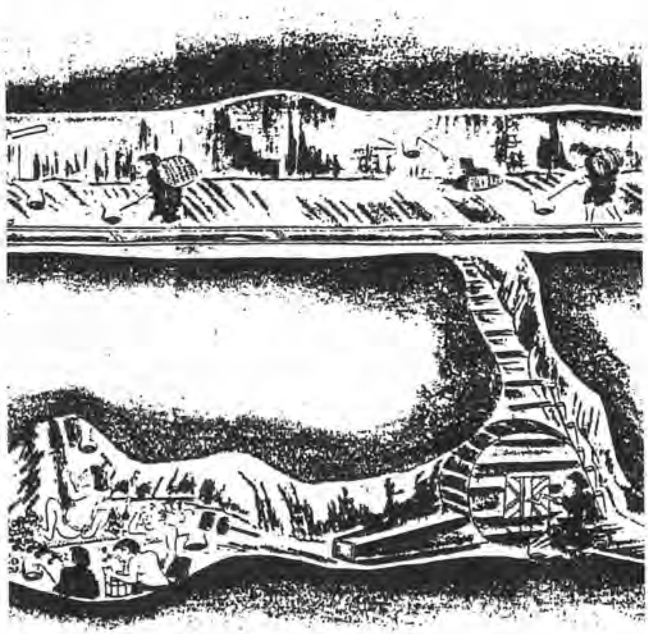


Fig. 95. A circular fan installation used for ventilation in a gold mine at Sado island in Japan as shown in a mid-19th century scroll. Treptow (1904), p. 22. See also Winkelmann (1957).

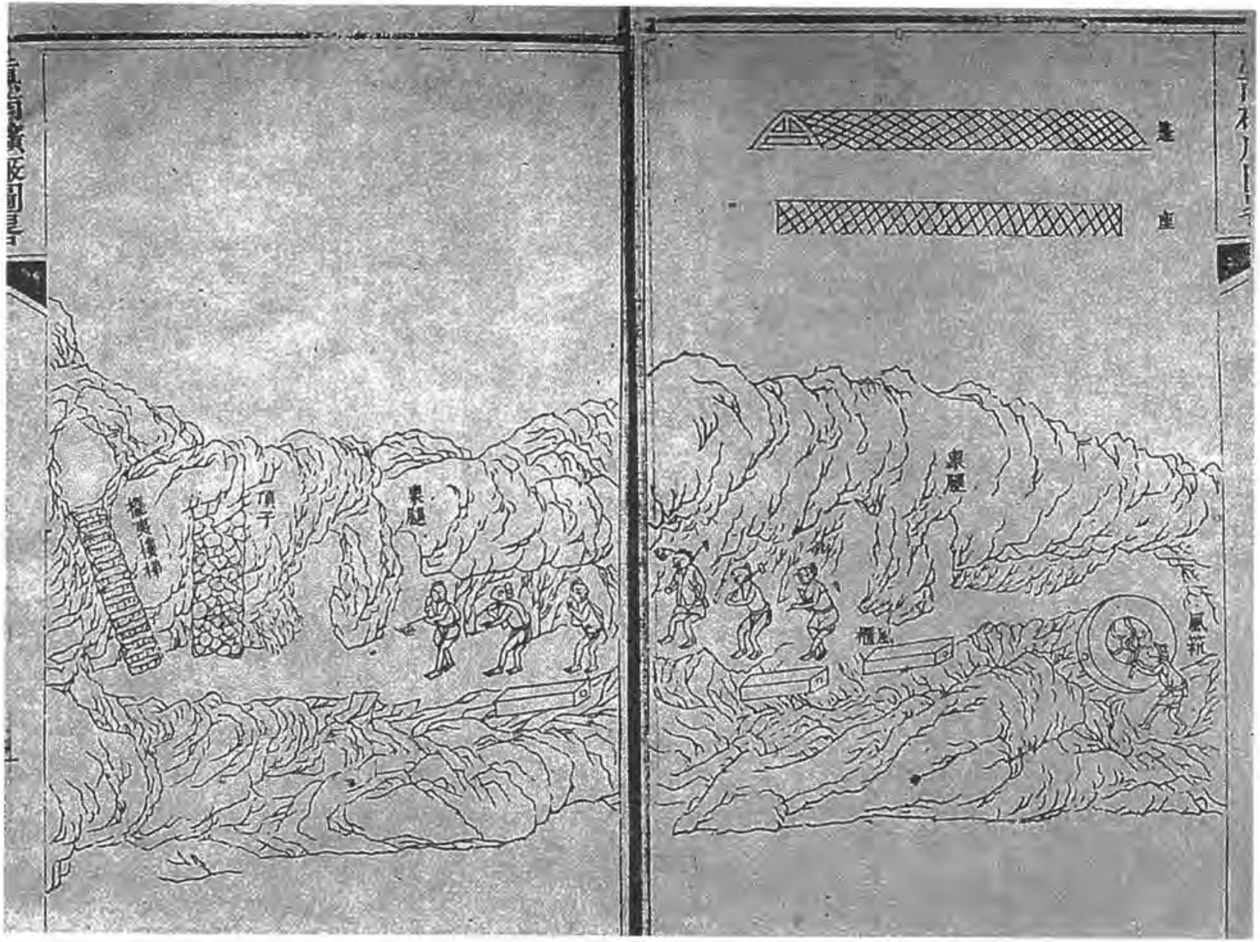


Fig. 96. Ventilation in a Yunnan mine using an enclosed circular fan and wooden (?) air ducts. Wu Chhi-chün (*1845*), Illustrations, pp. 1b–2a. According to Mark Elvin, the fan's air intake is at the hub; Elvin (1975), p. 87. The circle on the rim is apparently intended to indicate the vent. Curiously, the illustrator has portrayed the ductwork in discrete, unconnected sections. Unfortunately, there is nothing in Wu's text on the ductwork apart from the possible reference to it in the laconic statement that, after installing the fan (?), 'there is still a need further to set up the circulation of air' (*jeng hsu pieh khai thung feng* 仍須別開通風).

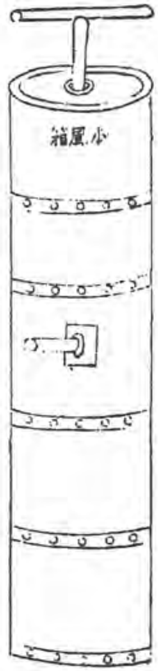


Fig. 97. A cylinder-and-piston ventilation pump used in Yunnan in the 19th century. Wu Chhi-chün (*1845*), Illustrations, p. 11a.

unfortunately, is poorly rendered and raises as many questions as it answers (Fig. 96). The illustration apparently represents an attempt by the artist to show the use of the circular fan (*feng hsiang* 風箱) together with square wooden air ducts (*feng kuei* 風櫃) though the ducts appear as discrete, unlinked sections.[265] By linking a number of fans at 25–30 m intervals, air could be forced along more than 100 m of shaft or drift, though about 150 m seems usually to have been the practical limit.[266] Such ventilation installations were of course limited to larger shafts where there would be enough space for the fans and the men who manned them.[267] Moreover, these shafts or galleries would have had to follow a fairly regular course; otherwise, any air flow would quickly be dissipated in twists and turns just as in the case of natural ventilation.[268]

Curiously, Wu Chhi-chün's work also includes an illustration of another kind of ventilation pump called a 'small wind box' (*hsiao feng hsiang* 小風箱) (Fig. 97) that

[265] The ducts could also be made of bamboo or of brick. Chhueh Liang-chhing (*1978*), p. 104; Su Ju-chiang (*1942*), p. 30. It should be noted that, in a not rare occurrence in Wu Chhi-chün (*1845*), there is a clear discrepancy between the labelling of the illustration, which clearly denotes the fan as a *feng-hsiang* and the text (p. 4a) that calls the fan a *feng-kuei*, explicitly noting that its form is similar to the back half of the box (*hsiang*) used in granaries for winnowing (*feng-mi*), and does not mention any *feng-hsiang*.

[266] On the other hand, Alexander Reid (1901–1902, pp. 31–2) describes a much grander and perhaps even unique pumping operation in a native coal mine near Chungking. The main adit, as we noted above (Section (*h*)(3)) was 6.5 km long; it was divided into 11 lengths, each with its 'separation door' where a fan 2.5 m in diameter forced fresh air into the next section.

[267] There seems no be no evidence suggesting that the motive power for the fans was ever anything but human muscle.

[268] Rocher (1879–1880), Vol. 1, p. 243.

unfortunately is not mentioned in the text. It is clearly a cylinder-and-piston pump and resembles in its general outward form the 'dragon pump' used for pumping water (Fig. 106, insert).[269] In contrast to the latter, however, it was equipped with what appear to be metal reinforcing bands and its outlet, in this case for air, is shown though it is surprisingly small. On the basis of the illustration alone, we cannot know how big this pump was or how it worked.

(11) Water Management

The presence or absence of water can be crucial in mining. Insufficient water can cripple mining operations or restrict them to certain seasons. Placer workings, for example, regularly came to a halt during those seasons when the streams were dry. In underground mines, water accumulations during the rainy season frequently brought an end to mining, which could resume only after the rains stopped and the accumulated water had been drained.[270] At the Ko-chiu tin mines in Yunnan, it was not mining but the concentrating of the ores that depended on the arrival of the annual rains in April or May.[271] By then, the miners would have excavated most of the ore to be processed for that year.[272]

Lack of water for mining or the concentration of ore was sometimes dealt with by diverting water from a nearby source. Sung Ying-hsing 宋應星 provides an example in the *TKKW* (Fig. 98):

> Mountain tin at Nan-tan 南丹 [Kwangsi] is found on the shady north side of the mountain.[273] As there is no water at the site for washing the ore, they join together a great number of lengths of bamboo into a flume (*chien shui* 梘水) and transport water from the south side of the mountain . . .[274]

It was too much rather than too little water, however, that was by far the greater problem for Chinese miners. Literary records as well as the remains of old mines reveal numerous cases where mining came to a halt because of excessive mine waters (Fig. 99).[275]

[269] Indeed, E-tu Zen Sun mistakenly identifies it as a water pump; Sun (1964), p. 122.

[270] As, for example, at the copper and the lead/silver mines in Szechwan; Robertson (1916), p. 269. At the remains of the Han copper mine at Kang-hsia in Hupeh, archaeologists have been able to conclude that the mine was worked for five or more years by identifying layers of debris brought in by water alternating with debris produced by the miners; Li Thien-yuan (*1988*), pp. 36–7.

[271] Scarcity of water, at least seasonally, was typical of Chinese tin mining districts; Watson (1930), p. 283.

[272] Golas (1991), pp. 263, 269. When the rains came too early, bringing to an end all open-pit and most underground mining, the miners would not have had an opportunity to excavate all the ore that could be processed; the result was less than optimal levels of production.

[273] 'Mountain tin . . . consists of tin melons and tin granules. Tin melons are about the size of small gourds while tin granules are the size of individual beans. Both can be obtained close to the surface with a minimum of digging.' *TKKW* 14, p. 240, my translation, assisted by Sun & Sun (1966), p. 251.

[274] *TKKW* 14, p. 241, my translation, assisted by Yabu'uchi (*1969*), p. 272 and Sun & Sun (1966), p. 251. Cf. also the irrigation flume illustrated in Vol. 2, pt. 2, Fig. 421.

[275] For just a few examples, cf. Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, pp. 678–9; Li Ching-hua (*1981*); Elvin (1975), p. 106; Couling (1917), p. 368; Shockley (1904), p. 855. As we shall discuss below, the importance of water problems as a brake on Chinese mining must be recognised but not exaggerated.

Fig. 98. Washing 'mountain tin' ore in baskets at Ho-chhih 河池, Kwangsi. Sun & Sun (1966), p. 254. This was an effective method for separating earth and clay from the ore and was probably used from an early period, for example, at Thung-lü shan 銅綠山; Hsia Nai & Yin Wei-chang (*1982*), p. 8. The insert, from a later version of the same illustration (*TKKW*, ch. 14, p. 260), suggests the flume (*chien shui*) by which the water was diverted was constructed of bamboo.

The problems posed by water are illustrated by the rough and ready distinctions Chinese miners sometimes made between different kinds of mine waters. Miners in the copper mines of Yunnan, for example, called water originating from a source outside the mine, such as a nearby river or stream, 'male water' *yang shui* 陽水. It was generally accepted that there was no way of handling this water effectively. Water

Fig. 99. Coal miners fleeing a mine where work will have to come to an end because they have broken through to substantial underground water. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 117, pl. 16.

originating inside the mine was 'female water' *yin shui* 陰水. If it constituted a major flow, it too was beyond control. Only moderate amounts of 'mineral nourishing water' *yang khuang chih shui* 養礦之水 could perhaps be managed in such a way as to permit continued mining.[276]

To some extent, drainage operations could be minimised by measures to block the flow of water into a mine or a working area. Early in this century, miners in Hopeh near the border with Shansi used wooden partitions made watertight with wool rags to keep out small amounts of groundwater.[277] Already in the Warring States period (–5th to –3rd centuries), miners at Thung-lü shan 銅綠山 were using

[276] Yen Chung-phing (*1957*), p. 59. We have discussed above (Section (*f*)(2)) the association Chinese miners made between the presence of water and rich mineral deposits, an idea that may have had its origin in experience with zones of secondary enrichment that occur below the water table.

[277] Junghann (1911), p. 12.

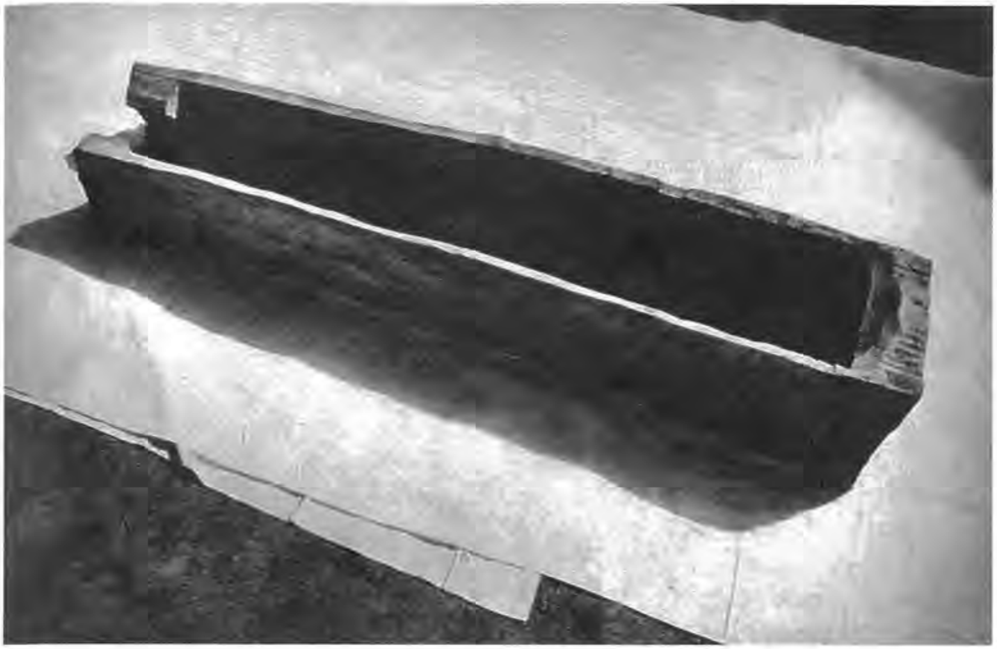


Fig. 100. Wooden drainage trough from Thung-lü shan 銅綠山, 1.6 m long, c. 0.3 m wide and c. 0.2 m deep. Anon. (1980), n.p.; Vogel (1982), p. 148. Other troughs ranged from 0.65 m to 2.6 m in length. They were sometimes linked in series with clay to make the joints watertight. Clay was also smeared along the bottom for the same purpose. Stabilising stakes were inserted alongside some of the troughs. Hsia Nai & Yin Wei-chang (*1982*), p. 6; Anon. (*1981*), p. 22. Four similar troughs (not illustrated) along with stabilising stakes (?) were found at the Thung-ling 銅嶺 mines; they ranged in length from 205 to 234 cm and were 28 to 32 cm in width. Liu Shih-chung & Lu Pen-shan (*1990*), p. 6. (Not all Chinese scholars are convinced that these were drainage troughs. Some argue that they were used for concentrating ores. See Chang Chao & Wang Kung-yang (*1988*), p. 70.)

kaolin or a clay and oil putty as a sealant for their wooden drainage troughs (Fig. 100).[278] Similarly, a putty of clay and oil kept sumpboxes watertight in 19th century silver mines in Mongolia.[279] Though various other sealants and ways of using them must have been tried from time to time, they could hardly have been effective against any but the smallest amounts of water. For the most part, miners probably simply put up with a certain amount of water just as they endured the foul air of the mines. It was simply one more element contributing to their more or less abominable working conditions.

Natural conditions sometimes cooperated to alleviate the need for drainage efforts. In some mines, such as the Fu-kho shan 斧柯山 mine at Tuan-chou 端州 (some 50 km west-southwest of Canton) which was famous for its Tuan-chhi 端溪 inkstones, temperatures at the great depths in which mining was already being

[278] Vogel (1982), p. 143; Hsia Nai & Yin Wei-chang (*1982*), p. 6; Anon. (*1981*), p. 22. Such troughs were also apparently used at the Jui-chhang mines; Lu Pen-shan & Liu Shih-chung (*1993*), p. 37.

[279] Dawes (1891), p. 335.

carried on by the late Sung (+13th century) fell low enough in winter and spring to freeze the water and thus permit mining.[280] Because the Yellowstone Pit silver mine in southwest Chekiang was driven into a steep slope of more than 50°, seepage of gound water into the mine could be minimised.[281]

Just as the actual mining itself, most water drainage efforts in Chinese mines relied above all on human muscle power. The most primitive means, suitable for dealing only with relatively modest amounts of water, employed boys or men to carry the water out of the mines in wooden buckets (Fig. 53), willow baskets, leather bags and the like.[282] Similarly, bucket brigades were sometimes organised, perhaps using a series of sumps.[283] These methods, similar to the way farmers above ground sometimes irrigated their fields, must have come into use very soon after Chinese miners first began to encounter underground water.[284]

Where the water had to be raised out of the mine, so-called 'water ladders' were sometimes used. These consisted of a series of sumps spaced vertically 1 to 1.5 m apart with the water ladled from one sump to the next (Fig. 54). W. A. Moller at the beginning of this century saw a mine in Manchuria where, he claimed, 150 men were raising water 150 m at the rate of 285 litres a minute or 17,000 litres an hour. This appears, however, to be very high. H. F. Dawes gives figures that work out to only 15,000 litres a shift, presumably the typical eight hour shift.[285] The same method was used (employing blind men) in Hopeh coal mines,[286] in the silver mines of Mongolia,[287] and undoubtedly in other mining operations in China. We can see essentially the same process in operation at an opencast tin mine in Malaya operated by Chinese miners where, however, it was used to raise ore sludge to the concentrating floors (Fig. 101).[288]

Probably the most common method of removing larger amounts of water from underground mines was to lead the water along inclined trenches or wooden troughs to a sump at the bottom of a shaft.[289] The water was then raised to the mouth of

280 *Yü Thang Chia Hua*, ch. 5, p. 3a. 281 Chhueh Liang-chhing (*1978*), p. 104.

282 Vogel (1982), pp. 148–9 and Anon. (*1975*), pl. 5, nos. 1 and 2 (Thung-lü shan); Woo Y. T. (Wu Yang-Tsang) (1902), pp. 755–6 (silver mines in Mongolia); Yen Chung-phing (*1957*), p. 59 and Li Chung-chün (*1982*), p. 3 (copper mines in Yunnan). The erratically winding excavations that typified so much of Chinese mining severely impeded the removal of water. Buckets could be brought out only very slowly. Moore-Bennet (1915), p. 215. For widespread use of this practice in late medieval and early modern Europe, see Braustein (1983), pp. 579, 583.

283 Woo Y. T. (Wu Yang-tsang) (1902), pp. 755–6.

284 Lu Pen-shan (*1990*) and Vogel (1982), p. 143, for drainage techniques at Thung-lü shan, where Warring States shafts penetrated as deep as 20 m below the water table; Zhou Baoquan *et al.* (1988), p. 127. Raising water may sometimes have been carried out by means of well-sweeps or swapes (*chieh kao* 桔槔) (Chang Ying-chhang (*1864*), ch. 25, p. 926; Elvin (1975), p. 106) but it is difficult to imagine many situations where this would have been both possible and useful, given the space they required. Furthermore, Alexander Reid (1901–1902, p. 29), describing a Honan coal-field, notes: 'They have small water-tanks, carrying about 15 gallons (57 litres), running on guides, and so arranged that they tip and empty themselves automatically, when they reach the top of the shaft.' This is less clear than one would like, but it seems to describe a method to which I have seen no other reference.

285 Moller (1902–1903), p. 139; Dawes (1891), pp. 335–6. 286 Pumpelly (1870), p. 292.

287 Dawes (1891), pp. 335–6 and Woo Y. T. (Wu Yang-tsang) (1902), pp. 755–6, 1038, which notes that the numbers of men used could make this an expensive method even with cheap labour.

288 Wong Lin Ken (1965), p. 283.

289 For early mines in which such troughs (or what seem to be drainage troughs) have been found, cf. Li Thienyuan (*1988*), p. 36; Anon. (*1981*), p. 22; Zhou Baoquan *et al.* (1988), p. 126. At Thung-lü shan, the miners used worked-out galleries and specially excavated small dimension galleries for drainage; *Ibid.*

Fig. 101. A Chinese open-pit tin mining operation in Malaya showing a long square-pallet chain-pump (centre), the ore concentrating installation (upper left corner) and the raising of the ore slurry from the bottom of the mine through a series of basin-shaped indentations cut into the wall of the mine (left); Wong Lin Ken (1965), p. 283.

the shaft by means of bucket and windlass (Fig. 102).[290] Unlike in central Europe where, in the late +15th century, mechanised windlasses powered by horses or by waterwheels were the harbingers of a wave of mechanisation that would soon transform much of European mining,[291] windlasses in Chinese mines overwhelmingly continued to be powered by human muscle right into this century.[292]

In some mines, especially in south China, the 'water dragon' (*shui-lung* 水龍) or square-pallet chain-pump, ubiquitous in the rice growing regions of China, was used for pumping water from underground mines though its size often prevented its use in narrow galleries (Fig. 101 and Fig. 103).[293]

If circumstances permitted and especially where there were large amounts of water to be disposed of, the galleries themselves or drainage tunnels and adits (*shui hsieh tsao tung* 水洩礲硐) might be driven slightly to the rise (i.e., at a slight angle upwards), allowing for a downward flow of water out of the mine.[294] Especially in

[290] Thus the same installation that brought ore or coal to the surface could be used for raising water. In the late 19th century, at the famous Khai-phing 開平 coal mine in Hopeh, three buckets of water had to be raised for every bucket of coal, probably the maximum effort that could economically be devoted to drainage; Wright (1984), p. 6. Excavators at Thung-lü shan have claimed to be able to distinguish shafts where no water was raised and shafts devoted exclusively to raising water, but their evidence appears to be insufficient to support such a clear distinction. Cf. Anon. (*1981*), p. 23.

[291] Braunstein (1983), pp. 584–6.

[292] For raising water, the Chinese seem always to have preferred windlasses, where the axis of the drum was horizontal, to whims with their vertical drums. Cf. Young (1970), p. 64, fn. 14.

[293] Lü Tai-ming (*1986*), p. 206; Slessor (1927), p. 56; Brelich (1904), p. 487.

[294] Wu Chhi-chün (*1845*), ch. 1, p. 21b; Kovanko (1838), p. 210; Pumpelly (1870), p. 292; Elvin (1975), p. 103; Brown & Wright (1981), p. 66.

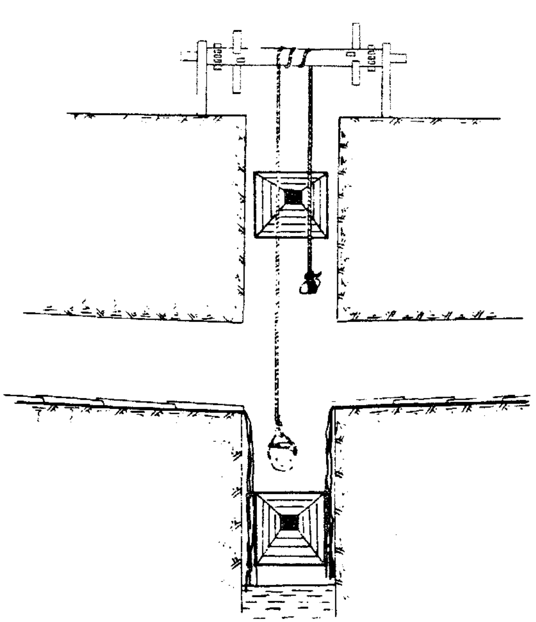


Fig. 102. Water-raising at Thung-lü shan 銅綠山 using a windlass and bucket. Anon. (1980), n.p.

Yunnan, the widespread mining of copper by means of adits (drifts) rather than shafts may have considerably eased drainage problems.[295] In certain kinds of mines, especially coal mines with well-located, thick seams, it was easy to drive workings at an incline so as to provide for natural drainage. Where adits had to be specifically driven for drainage, the savings they produced in the costs of water removal had to be balanced against the costs of driving the adit. Depending on the terrain and the location of the coal or orebody, those costs could be very substantial, even allowing for the considerable supply of cheap labour.[296] Just to repair a silted up adit something over 2 km in length at the Men-thou-kou 門頭溝 coal fields west of Peking, the Chhing government in 1801 appropriated 50,000 ounces of silver.[297] One can only speculate on the costs of driving a drainage adit at one Szechwan coal mine that ran for 6.5 km![298] Moreover, as Hollister-Short remarks, 'even the deepest adit could offer no more than a stay of execution against flooding.'[299]

[295] Vogel (1991c), p. 77.
[296] To some extent, the chronic shortage of capital in mining balanced out the advantages of cheap labour.
[297] Lü Tai-ming (*1986*), p. 206.
[298] Wright (1984), p. 6, drawing on Reid (1901–1902). Drainage adits were also used in the Yunnan copper mines; Yen Chung-phing (*1957*), p. 59. Of course, drainage adits could serve as well for hauling ore from the mine, possibly though not certainly resulting in further savings.
[299] Hollister-Short (1991), p. 192.

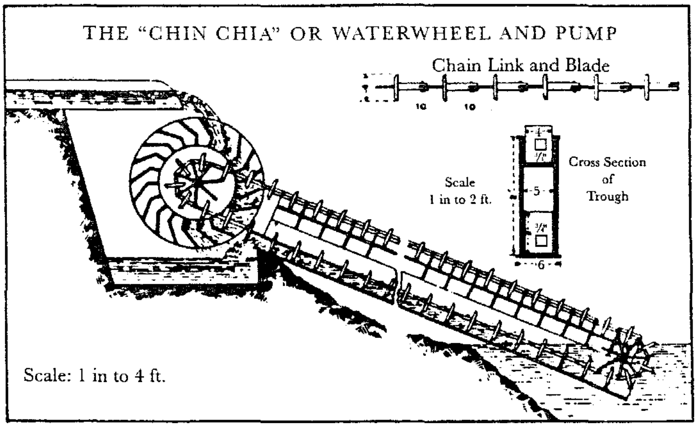


Fig. 103. A square-pallet chain-pump powered by an overshot waterwheel. Used by Chinese miners in Malaya. Note the clever combining of the stream of water powering the waterwheel and the drainage water in a single race whose water might well in turn power the waterwheel of another mine farther down the slope. Wong Lin Ken (1965), pp. 48–9 and p. 284, reproducing a diagram from P. Doyle, *Tin Mining in Larut*, London, 1879. Slessor (1927, p. 56) notes that, although these pumps could be as long as 5 m (15 ft), they had an effective lift of only 2–2.5 m (7–8 feet) maximum, since they had to be used on an incline. Their capacity was also limited to less than 1,900 litres (500 gallons) per hour.

In some cases, though apparently not very extensively, Chinese miners installed drainage pumps of various kinds.[300] For the most part, these were pumps that had originally been developed for other, especially agricultural, purposes. They were usually applied to mining without significant modification. This was true especially for the square-pallet chain-pump (Fig. 101 and Fig. 103), already mentioned above and perhaps the most widely used pump in Chinese mining. Mining operations as far flung as the Ko-chiu tin mines in Yunnan and the coal mines in northern Taiwan used square-pallet chain-pumps identical to those found on the farms in the same areas.[301] Three or four men working these pumps could raise water at a maximum rate of 13,600 litres per hour under the best conditions, but around 5,500 litres an hour was probably the norm. The maximum lift was 25 m but their efficiency dropped off significantly with lifts over 10 m[302] and the ideal lift was probably only about 3 m.[303] In Chinese tin mines in Malaya, waterwheels regularly provided the necessary power (Fig. 103).

[300] Mark Elvin has asserted an 'almost unchanging state of hydraulic technology' in the late imperial period (Elvin (1975), p. 86), suggesting that one reason was the relatively high cost of the materials such as metals and even wood necessary for their construction (Elvin (1973), p. 301). The general absence of pumps in Chinese mining even into the 19th century does seem to support his idea of cost constraints though he himself, in his later article (Elvin (1975), p. 86), appears to back away from assigning key importance to this factor.

[301] Hsieh Hsiao-chung (*1967*), p. 188; Brown & Wright (1981), p. 67, fn. 25. For details on these pumps, cf. Vol. 4, pt. 2, pp. 338–50 and Wong Lin Ken (1965), pp. 48–9, citing P. Doyle's account of 1879 that may be the earliest detailed description of a square-pallet chain-pump in English.

[302] Wong Lin Ken (1965), p. 56; Brown & Wright (1981), p. 67, fn. 25.

[303] Robertson (1916), p. 267: Reid (1901–1902), p. 35.

The absence of advances in pumping technology in late imperial times is underlined by the complete absence in Chinese mines of several kinds of pumps that played an important rôle in mining in the West. The first is the Archimedean screw or water-screw (*cochlea*) which was apparently in wide use at least for a time in the mines of Roman Spain.[304] Despite the availability of information on this pump (and even illustrations) by the +17th century at the latest as well as the clear belief of certain Chinese in the +18th and 19th centuries (e.g. Tai Chen 戴震 and Chhi Yen-huai 齊彥槐) that it was more efficient than the square-pallet chain-pump, there seem to have been no Chinese efforts to test its effectiveness in mining.[305]

The second kind of pump, what we might even better call a pumping machine, was also absent in traditional Chinese mines: the 'paternoster' or 'rag and chain' pump. As an explicit comment by Agricola and the several pages of *De Re Metallica* devoted to them attest, these pumps, which date from about +1430,[306] were very popular in +16th century central European mines, especially when large quantities of water were to be dealt with.[307] In these pumps, an endless chain pulled spaced pouches of leather filled with rags (or metal balls or discs) up the vertical barrel of the pump, with each of them acting as a one-way piston driving the water ahead of it to be discharged at the top (Fig. 104).[308] The efficiency and convenience of this kind of pump led to its displacing square-pallet chain-pumps throughout much of rural China in the 1950s but we have no evidence of its ever having been used in Chinese mines.[309]

In Europe, some 40 years after the rag and chain pump, the waterwheel driven bag hoist also made its appearance. It represented a whole new level of drainage capacity. Huge leather sacks made from the hides of four oxen could be drawn up from depths of well over 50 m by iron chains wound around a water-powered windlass.[310]

Related to the paternoster pumps in concept (though not necessarily in actual development) are various forms of cylinder and piston pumps which pulled water up through a vertical closed flume or cylinder. Here, however, instead of the endless

[304] Davies (1935), pp. 27–8.

[305] Vol. 2, p. 516; Vol. 4, pt. 2, p. 122; Elvin (1973), pp. 302–3; Elvin (1975), pp. 104–5. Hollister-Short is of the opinion that water screws probably were not used in post-Roman mining in Europe even though they are discussed in Renaissance books dealing with machines (personal communication). Bromehead (1942, p. 207) makes the same point, noting that there is no mention of them in Agricola's *De Re Metallica* (+1556) or in Kirchner's *Mundus Subterraneus* (+1664). This may partly have been because the Roman versions of the pump were clumsy and not very effective, being limited to a lift of only 1.5 m; Coghlan (1956), p. 21, citing Rickard. (Shepherd (1993), p. 40 says less than 2 m and suggests a water loss of 80%.)

[306] Hollister-Short (1991), p. 192. [307] Hoover & Hoover (1912), pp. 175–6; 188–97.

[308] An alternative version, from a century earlier than Agricola, is presented in Mariano Taccola's *De Ingeneis* of +1433 (Fig. 105) where the pouches are replaced by links similar in shape to mushrooms made of wood or thin and tinned iron; Prager & Scaglia (1972), pp. 76–7.

[309] Perhaps the 'chain' was the crucial problem here. If rope were used, as was sometimes done in Europe (Hollister-Short (1977), p. 131), the pump would be suitable only for light-duty lifting. If made of wood, it would probably not have been very durable. Metal chains, on the other hand, may simply have cost too much.

[310] Braunstein (1983), p. 585; Hollister-Short (1977), p. 129. In contrast, the 'limits of human forces applied to a windlass were reached at about 15 metres depth'; Braunstein (1983), p. 584.

Fig. 104. A simple paternoster pump (Hoover & Hoover (1912), p. 194). A drum (B) is mounted on an axle (A) that has been fitted with crosswise clamps (E) to catch the balls (D) attached to the endless chain (C). The water is emerging from a slot cut into the top of the pipe. This version is operated by two men, one at either end of the axle, just as the contemporary Chinese triple paternoster pump illustrated in Vol. 4, pt. 2, Fig. 585. Other versions described and illustrated by Agricola are powered by men in a treadmill, by horses and by waterwheels.

chain provided with balls or similar objects, a piston or disk or cone is attached to a rod by means of which the water is pumped upward with a reciprocating motion. These pumps too were very popular in Agricola's time, in part because at least some versions combined efficiency of operation with economy of manufacture.[311]

[311] Hoover & Hoover (1912), pp. 176–88, esp. p. 184. Such pumps first came into practical use in the mining industry in Germany some time before +1527 (Shapiro (1964), pp. 571–2) and, at about the same time, as bilge pumps on ships (Oertling (1989), pp. 584 and 594–5).

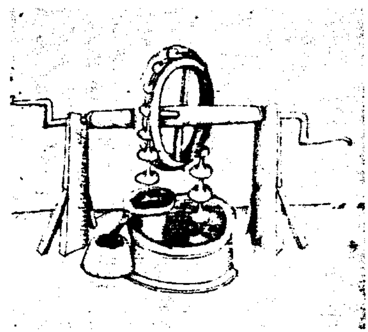


Fig. 105. An alternative to the rag and chain pump but using the same principle. From Mariano Taccola's *De Ingeneis* of 1433. Prager & Scaglia (1972), pp. 76–7. Taccola, after noting that this pump is 'in the manner of the Tartars', described it as follows: 'As you can see, [it has] a wheel placed over the well, with hanging attachments similar to mushrooms. The more [rapidly] it is driven, the more water is obtained. The links here, similar to mushrooms, or as we may better say, similar to spinning tops, must be made of rather strong wood, or of thin and tinned iron. . . . The wheel should be made six feet high. The spinning tops must pass through this pipe and be neither tight nor loose but must, throughout their motion, readily rise with the water.' *Ibid.*, p. 77 (with facing Latin text). I am indebted to Graham Hollister-Short for drawing my attention to this work.

None of these pumping machines lay beyond the reach of contemporary Chinese technology. Rather, their absence from Chinese mines seems due to non-technological obstacles such as the lack of the considerable capital necessary to construct them. It is only with the next advance in European mine pumping, the rod-engine (*Stangenkunst*)[312] that one sees a pumping machine that not only would have been prohibitively expensive at Chinese mines but also one whose mechanical complexity, at that time on the very edge of European capabilities,[313] was and may well have remained beyond what Chinese mechanics could have built *and maintained* at any time before this century.

Given the generally sparse useage of pumps in Chinese mining as well as the fact that traditional Chinese technology made abundant use of piston air-pumps, especially the well-known and ubiquitous box-bellows,[314] but rarely used cylinder and piston pumps for liquids,[315] it is not surprising that we find almost no evidence for the use of cylinder and piston pumps for mine drainage.[316] This is equally true whether one looks for force pumps, where the water is entirely or mainly forced upwards by mechanical action, or suction pumps where it is primarily atmospheric pressure that raises the water.[317] Indeed, there seems to be nothing before the

312 Hollister-Short (1991). 313 *Ibid.*, p. 194. 314 Vol. 4, pt. 2, pp. 135ff.

315 The most dramatic exception is the very sophisticated flamethrower devised in the Sung; Vol. 4, pt. 2, pp. 144–9; Vol. 5, pt. 7, pp. 81ff.

316 S. Wells Williams (1840, p. 90) could comment at that time that the 'lifting-pump is not known to the Chinese', a statement that we need not take literally (he is not likely to have been in many, if any, mines) but which does suggest rather strongly that they were not common.

317 Shapiro (1964), pp. 566–7.

mid-19th century[318] when Wu Chhi-chün not only describes the use of cylinder pumps, called 'dragons', in the copper mines of Yunnan but even provides us with two illustrations of them (Fig. 106):[319]

The dragon [pump] is made of bamboo or wood and is eight to sixteen feet long, hollow inside, and with [an inner?] diameter of four to five inches. There is also a wooden or iron rod [i.e. plunger] of the same length to which is joined a piece of leather that has been cut to form a 'cushion' (*tien* 墊).[320] For each dragon, there is for each shift one pumper and one alternate. . . .

This is, of course, a less than complete description.[321] A crucial question is whether these force pumps, like the flamethrower mentioned in note 315, were also partially vacuum or suction pumps.[322] Conceivably, a partial vacuum was created on the upstroke (the leather fitting tightly against the walls of the cylinder). The vacuum drew water into the lower part of the cylinder through one or more flap-valves in an otherwise sealed bottom. On the downstroke, the water somehow (perhaps using another flap-valve) passed through to the upper chamber, where it was raised by the mechanical action of the following upstrokes. The result would be a combination force/suction pump. This explanation can only be tentative, however, since neither of Wu Chhi-chün's illustrations shows flap-valves. On the other hand, if the leather cushion exited the cylinder on each downstroke, as shown in the insert illustration of Fig. 106, the cylinder would have had to contain some kind of sleeve or other guide arrangement through which the rod moved. Otherwise, the free movement of the rod when the cushion exited the cylinder would have made operation of the pump extremely if not impossibly clumsy. There is, however, no suggestion in the illustration or the text of a sleeve assembly.[323] Moreover, the rod in that case would have had to be *longer* than the cylinder and not the same length, as the text explicitly describes it, thus directly contradicting the insert illustration that shows a rod clearly longer than the cylinder. On the basis of Wu Chhi-chün's description, then,

[318] Lü Tai-ming (*1986*, p. 205) argues for the likelihood that water pumps were used in coal mines in Szechwan as early as the Sung, given the use of bamboo tubes equipped with a flap-valve that were used to lift brine out of salt wells there by at least that time. He also cites the well-known description of the same use in the +17th century *TKKW*. This interpretation, however, fails to distinguish clearly between lowering and raising a kind of container in order to extract a liquid and the use of a true pump.

[319] Wu Chhi-chün (*1845*), ch. 1, p. 4b; my translation, assisted by Elvin (1975), p. 101 and Sun (1964), p. 64. Elvin calls these pumps 'pulling dragons' after the label (*la lung* 拉龍) in the illustration, but the text makes clear that they were simply called dragons (*yueh lung* 曰龍) so that *la lung* refers to the activity of working the pumps; cf. Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 630; Wu Chhi-chün (*1845*), ch. 1, p. 21b.

[320] For examples of such 'cushions' from +16th century European suction pumps, see Oertling (1989), pp. 590–4.

[321] One point on which it is clear, however, is the exclusive use of wood or bamboo to construct these pumps. Cylinder and piston pumps did not need to be made of metal, as suggested by Elvin (1973, p. 302).

[322] It is significant that a German observer of what seem to be very similar pumps calls them 'suction-pressure pumps' (*Saug-Druckpumpen*); Esterer (1929), p. 148. Vogel takes similar pumps in Japanese mines to be true suction pumps and suggests that this may also have been the case for the Yunnan pumps, though that is by no means certain; Vogel (1991c), pp. 77 and 95, fn. 20. Contrast Elvin (1975), p. 100, fn.

[323] However, when we compare this illustration with the illustration of a ventilation pump that we saw above (Fig. 97), we note that the opening for the plunger at the top of the cylinder in the ventilation pump is much smaller so that it could have served as a guide for the sliding plunger. One more similar piece at a suitable point on the inside of the cylinder might have been able to keep the rod in line when exiting the cylinder at the bottom. In the absence of any evidence to support such a reconstruction, I consider it an unlikely possibility.

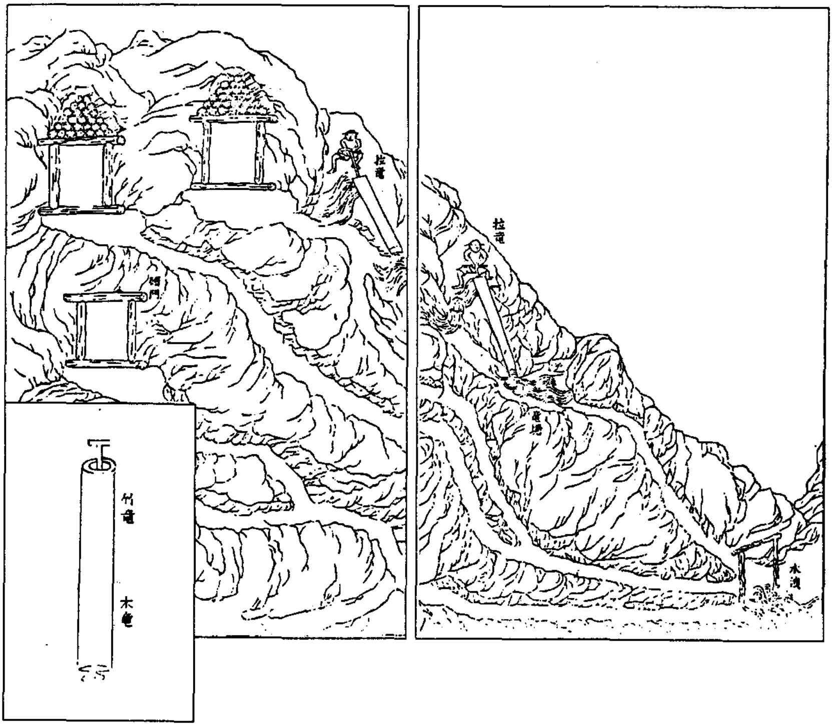


Fig. 106. Two 'dragon' pumps in a Yunnan copper mine; Wu Chhi-chün (*1845*), Illustrations, pp. 3b–4a. (The illustration is meant to portray the *inside* of the mine.) In contrast to the description in the text, the pumps probably mistakenly appear here to have a diameter significantly greater than 10–12 cm. Also, the larger drawing shows only one of the men in the two-man teams that alternated in working each pump. The insert drawing (*Ibid.*, p. 11a) is probably incorrect in suggesting that the leather cushion exited the bottom of the cylinder on the downstroke. Note further than the 'water outlet' (*shui hsieh*) in the lower right corner together with the distance between the two pumpers suggests that, in contrast to Fig. 107, the water here is being pumped directly into a drainage adit rather than being raised in steplike fashion until it reached the level of the drainage adit. It seems unlikely that there could have been many circumstances where the conditions of the mine would have permitted such a procedure.

and without further data, it seems impossible to decide precisely how these pumps functioned.[324]

Where large quantities of water had to be drained, up to 13 or 14 pumps might be deployed in a row at the same level. Depending on the height that the water had to be raised, it might be pumped through many levels. The maximum in Yunnan seems to have been 50 or 60 levels[325] though we have one +18th century Japanese

[324] The kind of analysis one might undertake with better quality evidence is brilliantly exemplified by Graham Hollister-Short's examination of the origin of the suction pump in Western technology; Hollister-Short (1993).

[325] *TNKC*, ch. 1, pp. 4b–5a; Sun (1964), p. 64; Elvin (1975), p. 100.

example where the water was pumped through 130 levels (Fig. 107)![326] Such pumps also appear to have been used in mines in Hunan at least by the beginning of this century.[327] Judging from the description given by Maximilian Esterer, the pumps were apparently very similar to those used in Yunnan except that their handles were somehow outfitted so that the pumpers could, 'in a rowing motion' (*ein Art von Ruderbewegung*), accomplish eleven 40 cm strokes a minute while sitting down![328] Moreover, four or five pumps were regularly *linked* in parallel and brought up about 13 litres of water with each stroke, or about 120 litres a minute, which was just marginally better than a single square-pallet chain-pump.[329] Esterer is not clear on how many men worked these four or five pumps. However, since they seem to have been about the same size as the pumps used in Yunnan (Esterer gives 3–4 m for their length), the best guess would probably be one or two men per pump, making this installation seemingly less cost-effective than the old standby square-pallet chain-pumps. Why then were these pumps used so extensively in the Yunnan copper mines? We seem to lack any hard evidence on this point; perhaps Wu Chheng-ming and Hsu Ti-hsin are correct in suggesting that it was both because the Yunnan mining environment made it difficult to set up square-pallet chain-pumps and because the ore deposits were sufficiently rich to justify the cost of cylinder and piston pumps.[330]

Where mining came to a halt because of drainage problems, the real cause was not always an inability to handle the amounts of water involved. Chinese miners, even with their relatively primitive techniques, were sometimes capable of dealing with quite substantial quantities of water. For example, the virtually unlimited coal resources in Chang-te fu 彰德府, An-yang 安陽 hsien (Honan) were exploited at considerable depths (up to several hundred *chang* 丈, that is, perhaps 1,000 m) during the Ming even though all the coal lay below the water level, thus necessitating water removal before it could be mined.[331] As early as the Warring States period, the workings at Thung-lü shan 銅綠山 were pushed to 20+ m below the water table.[332] Large quantities of water, however, could be countered only by major and continuing investment of labour power, whose costs could easily outrun what the production of the mine could support.[333] This was precisely the case in certain Yunnan

326 Smith (1983), p. 4; this Besshi 別子 mine, on the island of Shikoku, exploited the largest copper ore deposit in Japan; Kroker (1984), p. 9.

327 Junghann (1911), p. 12 and Esterer (1929), pp. 148–9.

328 For suggestions of how this might have been done, cf. Vol. 4, pt. 2, Figs. 575 and 580.

329 Compare Vol. 4, pt. 3, p. 666.

330 Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 630; Robertson (1916, p. 267) notes the use of what seem to be similar pumps in Szechwan mines early in this century and found them 'good for lifts up to 24 feet'.

331 *Chang-te Chih*, cited in Wang Chung-lo (*1956a*), p. 29.

332 Zhou Baoquan *et al.* (1988), p. 127; Ho Ping-chang (*1984*), p. 644. The earlier report, Lu Mao-tshun (*1974*), gave a more conservative 10 m.

333 In late medieval and early modern Europe, by contrast, the much more limited availability of cheap labour led to a great burst of innovative use of machines to deal with mine waters between the +14th and the +16th centuries. Of the more than 150 mining innovations identified by Danuta Molenda for this period, 90% were designed to improve the drainage of water from mines; Molenda (1988), p. 73. Interestingly, once most of the mechanical and gravitational devices for handling water had been devised – mainly by the middle of the +16th century, there seems to have been little need felt for improvements in other areas of mining, and technological innovation declined sharply; *Ibid.*, p. 74.

Fig. 107. A woodblock illustration from the Japanese 'Illustrated Book on the Smelting of Copper' (*Kodō-zuroku* 鼓銅圖錄) showing a copper mine, c. 1800, where pumps similar to the Chinese dragon pumps (cf. Fig. 106) were used in series to raise water to the level of a drainage adit. Smith (1983), pp. 34–5, pl. 4; cf. Kroker (1984), pp. 28–9; Anon (1909), pp. 13–14. Note that the pump frames here are made of wood and not bamboo though the caption explicitly says that either could be used. The artist also portrays two curious protrusions near the top of each pump. They are not mentioned in the caption and it is difficult to imagine what their purpose might have been. For a +1769 illustration showing 27 of the 130 piston pumps and pump operators that raised water 220 metres to a drainage adit in the Besshi mine, see Smith (1983), p. 4. Here, the pump operators were paid 4.9 *sen* for each thousand strokes or about 7,500 litres raised; *Ibid.*, p. 15.

copper mines where over 2,000 workers might be used daily in the drainage of a single mine, leading the miners to petition the government for a subsidy to help with drainage costs (*shui hsieh fei* 水洩費).[334] Eventually, these subsidies were regularised and, after +1772, were tied to the production levels of individual mines. In 1807, the eight mines for which we have figures received from 522 ounces of silver (based on a production of 80,000 *chin* or just over 50 tonnes of copper) to 4,915 ounces of silver (based on a production of 2,900,000 *chin*).[335]

Discussions of the inability of traditional miners to handle large amounts of water regularly seem to presume that, had this problem been solved, mining could have continued in essentially the same manner to ever greater depths.[336] This is far from universally true, however. Otis E. Young catalogues a number of ancillary problems that Mexican silver miners encountered as they began working below the water table, including: a harder quartz gangue that had been protected by the water from weathering and decomposition; a sharp decline in the tenor of the ore because, again, the water had protected it from weathering and the natural concentration that weathering produces; a change in the nature of the ore from relatively easily processed chlorides to sulphurets (sulphides) of silver that were complicated and costly to smelt. He notes that, even in modern times, 'wherever ore persists in depth, striking the water table automatically ends bonanza [the relatively easy and profitable mining of naturally concentrated oxidised ores] and necessitates complete and costly revision of the whole operation.'[337] Though Young is discussing silver mining, many of the same or similar problems will be met with in other kinds of mining that penetrate below the water table. We should therefore avoid overstressing water management as the only reason for abandoning mining operations while at the same time recognising that the inability to handle the water probably more often than not saved Chinese miners from encountering these ancillary problems.

H. Foster Bain argues from another perspective that the inability of miners in China to handle water problems has been overemphasised as an explanation for the abandonment of mines:

> . . . one who has crawled and squirmed through old Chinese workings to depths of 600 or 800 feet can hardly escape conviction that mining ceased in depth often for the same reason it has elsewhere; namely, impoverishment of the particular ore shoot followed from the surface and failure to find another by a limited amount of cross-cutting. In most cases the wonder is not that the miners have stopped where they did but that they were able to penetrate so far and won so little from their efforts.[338]

[334] Chang Ying-chhang (*1869*), ch. 25, p. 930; Elvin (1975), p. 106; Yen Chung-phing (1957), p. 60.
[335] Vogel (1987a), V.3.c. [336] E.g., Read (1912), p. 41. [337] Young (1970), pp. 73–4. [338] Bain (1927), p. 218.

(*i*) ORE DRESSING

(1) THE ORE DRESSING PROCESS

Before being sent to the smelter, most excavated ores require an intermediate processing that can range from very simple to quite complex. The main goal is to separate the desired material from the waste materials, the 'gangue', associated with it, thus producing a 'concentrate'. The waste materials discarded after processing are generally referred to as 'tailings'.

Sometimes, ore dressing must separate two ores that cannot be metallurgically treated together (e.g. lead and zinc ores). In the case of metallic ores, it can be especially important to produce as pure a concentrate as possible or economically feasible so as to maximise the results from traditional smelting procedures that were often very inefficient.[1] Rendering the pieces of ore roughly the same size was also necessary for even relatively efficient smelting methods.

The complex of processes used to accomplish these ends is most commonly referred to as ore dressing, beneficiation, ore concentration, ore processing or mineral separation.[2] I have tended to use, interchangeably, the first three of these terms when referring to these processes. In China, ore dressing (*hsuan khuang* 選礦) was commonly viewed as an integral part of mining and was usually carried on at or near the mine site, or even inside the mines.[3]

The various steps that can make up the ore dressing process are presented in Fig. 108. The mix of steps will vary according to the nature of the ore being dressed, and seldom will all the possible steps be used for a single ore.

The first step in ore dressing was frequently a rough sorting or hand-picking of the ore, perhaps after washing it to remove earth and clay. In underground mining, rough sorting at the working face had two advantages: (1) it minimised the amount of material to be removed from the mine; and (2) it provided a ready supply of waste material that could be used to fill in and shore up abandoned workings where necessary.[4] It is such an obvious first step in ore dressing that it must have been practised from the beginnings of open pit and underground mining, in China as elsewhere.[5] The remains at one of the excavated Thung-ling 銅嶺 mines of what has been identified as a wood(-lined) chute (*mu liu-tshao* 木溜槽) together with a tailings pond (*wei-sha chhih* 尾砂池) (Fig. 109)[6] and which has been radiocarbon dated to about −600 may well have been used for some kind of ore washing.

[1] Sun (1964), p. 65. Accomplishing the smelting using a minimum of costly fuel was always a high priority. Ludwig (1978), p. 140; Molenda (1988), p. 88.

[2] The various processes such as breaking, milling and crushing which aimed at reducing the size of the ore pieces are sometimes called 'ore reduction'.

[3] Dawes (1891), p. 335. [4] Verschoyle (1906), p. 919.

[5] Brown (1923, p. 132) found the Chinese in Yunnan 'very expert' at this task.

[6] Liu Shih-chung & Lu Pen-shan (*1990*), p. 6.

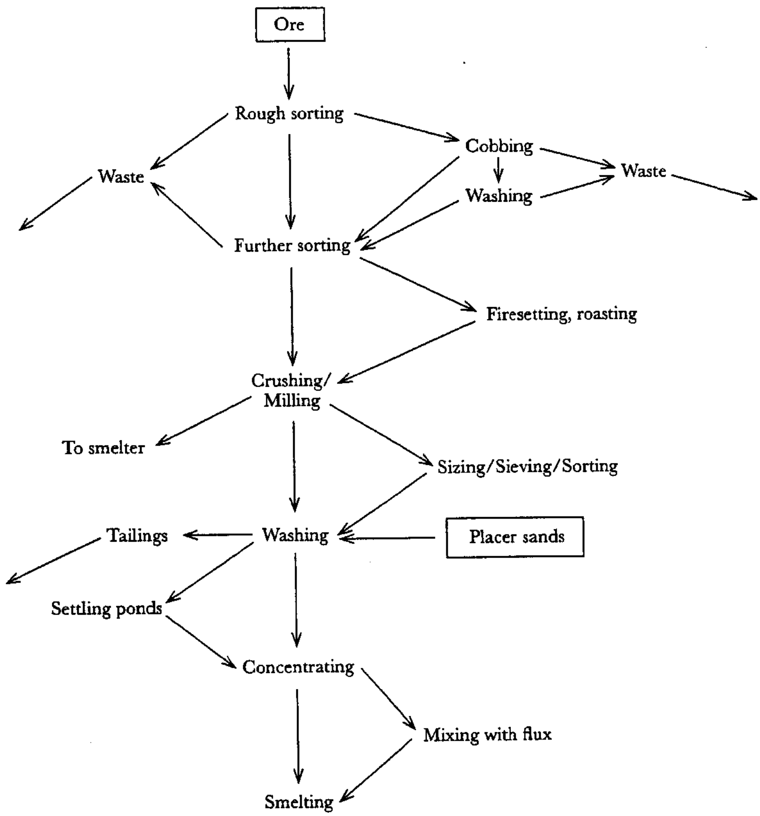


Fig. 108. Basic steps in the ore dressing process.

Cobbing, too, either in the mine or nearby, was a part of the mining process. It consisted of breaking larger pieces of ore with a stone or hammer in order to facilitate the removal of gangue.[7] Washing might also be used before or after this step to get rid of clay or mud. These were processes frequently performed by women or children. For certain products, such as coal, dressing was completed with this step; the coal was now ready for sale.

Once ores had been visually sorted, they were ready for the next step, one of the most costly in the whole mining process.[8] This involved crushing or grinding the ore into pieces of a standard size that could be sent to the smelter or pulverising it

[7] Not surprisingly, these sorters often became very skilful at their task; Slessor (1927), p. 62.
[8] United Nations (1972), p. 34.

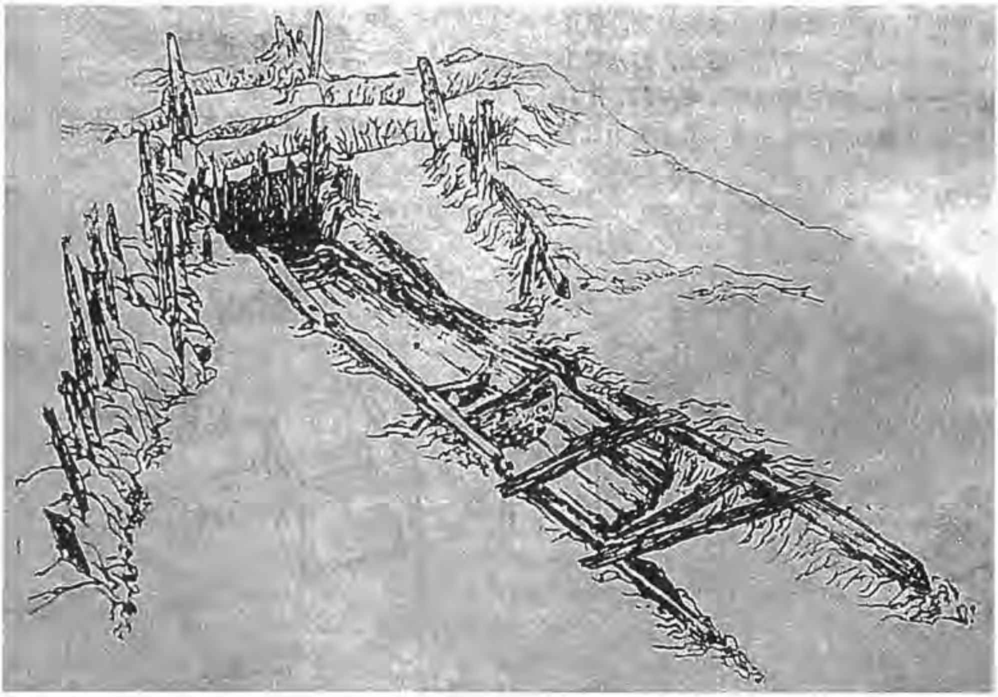


Fig. 109. A wood-lined chute (*mu liu-tshao* 木溜槽) together with a tailings pond (*wei-sha chhih* 尾砂池) excavated at Thung-ling 銅嶺 and dated to approximately −600. Liu Shih-chung & Lu Pen-shan (*1990*), p. 6. Noel Barnard describes it as follows: 'The chute . . . was faced with large round timber and formed a [semi-]circular structure 3.43 m in length, 34–42 cm in width, and was covered with cross-pieces (檔板 *tang-pan*) 2 cm thick and 10 cm wide fitting into grooves (相嵌 *hsiang chhien*) along the eastern sides of the chute wall, and dovetailing into the western sides. At the end (尾 *wei*) of the chute was a removable (活動 *huo-tung*) retaining cross-piece of semi-circular shape (42 cm wide, 1.5 cm thick). It was set in grooves in the western sides of the chute wall and fitted precisely against the curvature of the eastern wall of the chute. . . . The tailing pit was located at the end of the wood-lined chute, the bottom of the pit and the end of the chute were connected by a terrace upon which wooden planks of 10–14 cm width were spread, but there was no such wood covering on the pit bottom. The eastern, southern and western walls of the pit were held in place by facings of round timber. The depth of the pit was 76 cm with sedimentary layers of mainly red-brown iron clay and a glossy earth.' Barnard (1995), pp. 16–7; Anon. (*1990*), p. 6, fig. 9.

into even smaller particles that could be concentrated by washing. Crushing and pulverising iron ore was in use at least as early as the Han, and in all likelihood earlier. Excavations at a Han iron mining and smelting site discovered on the northwest outskirts of Cheng-chou 鄭州, Honan, revealed one heap of iron ore 'broken up and sifted to a grade of 2.5 cm' and another of crushed ore.[9]

Most of the crushing and pulverising was carried out using a range of tools and machines the same as or similar to those that had been developed for the grinding of grain or other agricultural tasks: mortars; horizontal millstones powered by men, by animals or by water; and edgerunner or Chilean mills.[10] Stamp mills, some

[9] Actually, this is just one of many Han sites where evidence for the sifting and crushing of ore has been found; Anon. (*1978e*), p. 10.

[10] Verschoyle (1906), p. 919; Read (1907), p. 1297; Louis (1891), p. 641; Su Ju-chiang (*1942*), p. 33; Draper (1931), p. 185.

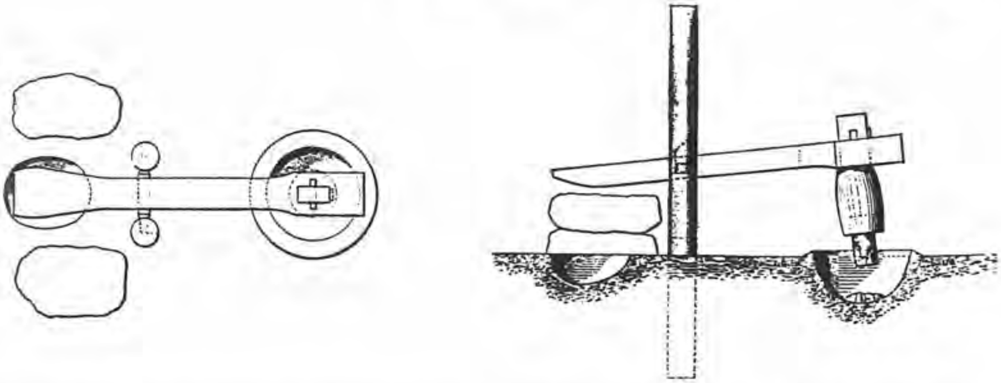


Fig. 110. Typical foot-powered quartz-crushing mill used by Chinese gold miners at Tomoh in Malaysia from about the mid-19th century. It was constructed entirely of wood with the exception of the hammer head, which was fashioned out of hard quartzite. With a falling weight of about 20 kg (45 lbs), a distance of fall of about 50 cm (20 in) and a rate of operation of between 15 and 20 blows per minute, a single mill could crush from 31 to 62 kg (70 to 140 lbs) per eight-hour day, according to the hardness of the rock. Louis (1891), pp. 640–1; Louis (1892), p. 629. Pottery tomb models from the Han dynasty (–2nd to +2nd century) include virtually the same machine. Cf., for example, Needham (1964a), pl. 23, facing p. 278.

foot-powered (Fig. 110),[11] some consisting of several hammer heads powered by a waterwheel (Fig. 111), were also used. There seems to be no evidence to indicate whether Chinese miners shared the general preference of 19th century California miners for the faster stamp mills in preference to Chilean mills.[12]

The crushing of ore could be facilitated by the application of heat. Firesetting could be as helpful here as in the mining process itself.[13] Roasting, which was often necessary to rid a 'harsh' ore of sulphur, arsenic, antimony, etc. in preparation for smelting, also served to make ore brittle and therefore easier to crush.[14] After crushing, the ore might be sifted to provide a finer product that would permit more effective concentration by washing. Chao Yen-wei, writing in the first decade of the +13th century, describes the dressing of silver ore in Fukien: 'The ore is obtained as gravel-sized rocks which are crushed in a mortar. These pieces are then ground. The resulting powder is sieved through silk, and what passes through is washed. The brown powder is gangue and is discarded. The black powder is silver concentrate . . .'.[15]

Washing or panning was often the final step in ore dressing. The purpose and methods of this washing were essentially the same as in the washing process at placer deposits.[16] Here, however, much larger quantities of material were frequently dealt with and the washing methods and facilities were correspondingly more elaborate (see Fig. 38; Fig. 40; Fig. 101; Fig. 113; Fig. 114). For example, the Chinese tin miners in 19th century Malaysia used very large sluices 6–10 m in length, 60–90 cm wide and 30–60 cm deep. An operation of this size required seven men to operate it: three to

[11] Slessor (1927), p. 62.

[12] Paul (1963), p. 32. For a discussion of Chinese pounding, grinding and milling tools and machines, see Vol. 4, pt. 2, pp. 183–204.

[13] Read (1907), p. 1297; Louis (1891), p. 640. Cf. also Section (*h*)(6) above.

[14] Smith (1967), p. 146.

[15] *Yun Lu Man Chhao*, ch. 2, p. 48; Hua Jueming (1989), p. 3.

[16] Cf. above, Section (*g*)(1)(i).

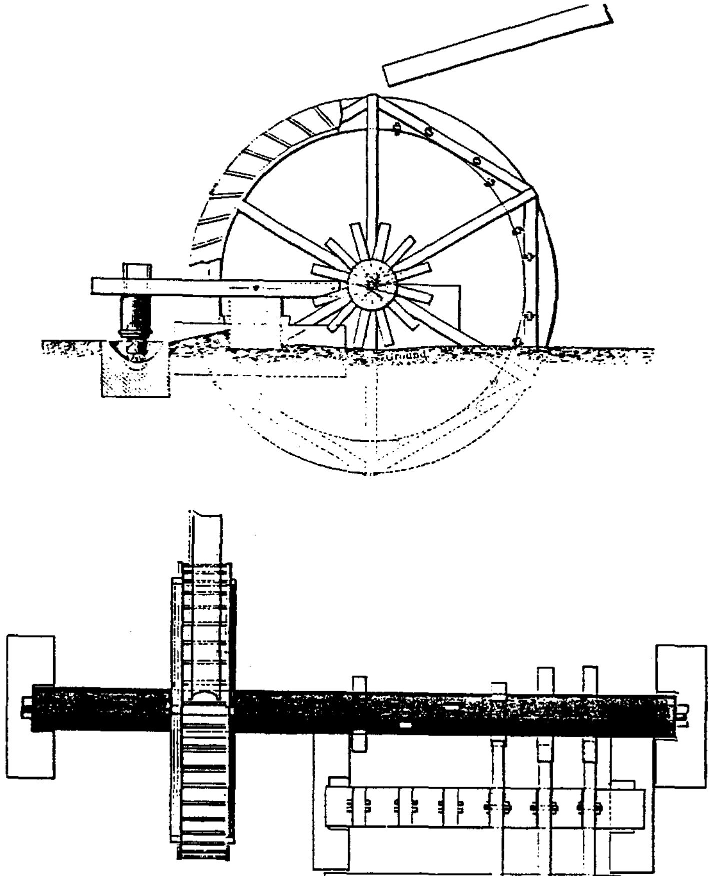


Fig. 111. Water-powered quartz crushing mill with six stamps used by Chinese gold miners at Pacho near Tomoh in Malaysia, late 19th century. The number of heads varied according to the availability of water, but six were common in this area. Louis points out that 'the construction of the water-wheel is extremely crude – the water, which is sometimes brought down very steep hills from considerable heights in small, steeply-inclined ditches, strikes the flat buckets with considerable velocity, so that the wheel is partly an impact and partly a pressure wheel; the buckets are never more than half-filled at the best, and the wheel is sometimes allowed to wade in tail-water to the full depth of the shrouding. Much power is accordingly wasted, the amount of water consumed in driving one of those mills being from 80 to 100 cu. ft per minute. The average number of drops of each head varies between 28 and 32 per minute; the length of the drop is about 2 ft, and the effective falling weight of the head is about 70 lbs. Thus only about one-third of the theoretical power of the machine is utilized, but of course much of this loss of energy is due to the friction of the whole machine, notably between the straight cam and the tail-piece of the hammer.' The hammers had to be replaced after anywhere from a week to a month. Louis (1891), p. 641; Louis (1892), p. 629. For a detailed discussion of a Roman waterwheel used at the mines in Rio Tinto in Spain, see Weisgerber (1979).

feed it and remove debris, and four to agitate the tin dirt by raking.[17] The scale of washing for purposes of ore dressing also introduced another difference: where placer deposits ordinarily (though by no means always) had more than enough water for washing available in the immediate vicinity, providing sufficient water for the washing of large quantities of ore from open cast or underground workings has, from earliest times, been one of the most prevalent problems of mining the world over.

(2) Tin Ore Dressing at Ko-Chiu

Nowhere was water more crucial to mining than at the major tin production centre of the Chhing (+1644 to 1911), Ko-chiu 箇舊. Most of that water was required for the elaborate ore dressing processes employed there.

Besides the cassiterite present in crystalline form, much of the Ko-chiu ore consisted of very fine granules.[18] Separation of these granules from their surrounding matrix of worthless materials was especially difficult. This helps to account for the elaborate repertoire of washing devices and procedures which represent a kind of culmination of Chinese technological practice using premodern capacities based solely on long experience.[19]

The rainy season at Ko-chiu usually began some time around the fourth lunar month (May) and ended around the eighth month (September). Important for the miners and smelters was not only the length of the rainy season but also how much rain fell and the nature of that rainfall. If the rain came too early, production would be hurt because the miners would not have had time to amass as much ore as could be concentrated during the rainy season and afterwards. Too heavy rainfall could damage the reservoirs and the ditches through which the water flowed into them. In a year of light rainfall, ore dressing might have to be curtailed for lack of water.

The dressing of lode ore from underground workings began with sorting and cobbing. Large pieces of ore and waste were first broken up with clubs or flails or iron hammers. Most of the ore disintegrated quite easily into a granular, sandy product ready for washing.[20] For the remainder, which might be about 10 per cent of the total ore, sieves were used to select out the pieces small enough for crushing and milling while what was left over would be returned for further hand breaking. The crushing and milling were accomplished with horizontal millstones, foot stamps, or edgerunner mills powered by animals or by the miners themselves.[21]

[17] Wong Lin Ken (1965), p. 50. [18] Chhen Ping-fan (*1954*), p. 185.

[19] Even with this elaborate technology, certain deposits could not be worked because they contained considerable amounts of clay and would therefore require too much water to remove the clay by puddling; Collins (1909–1910), p. 209.

[20] Draper (1931), p. 184.

[21] Su Ju-chiang (*1942*), p. 33. Draper describes these 'Chilean' mills with their wheels 'composed of a centre of granite about 9 ft. in diameter, and 8 in. thick at the centre [hence much larger than the wheels on the edge-runner mills in Vol. 4, pt. 2, Figs. 453 and 454], tapering to an edge on which a cast iron rim 6 in. thick and 6 in. wide is wedged and leaded. The weight of such a wheel is about two tonnes. It is placed in an upright position and has a horizontal axle coupled to a vertical post.... The race, 20 ft. in diameter, is lined with heavy stones and sometimes iron castings. A water buffalo, harnessed to the outer end of the horizontal axle, furnishes the motive power. The crushing is well done but is slow and expensive.' Draper (1931), p. 185.

The many different processes or combinations of processes used to further separate and concentrate the granular or milled ore all relied on the high specific gravity (6.8–7.1) or weight per unit volume of cassiterite which meant that, in water, the cassiterite would tend to sink to the bottom while its associated materials would remain suspended or float to the top. The simplest method of separating out the cassiterite was panning or washing. We have seen above (Section (*g*)(1)(ii)) that panning can be a remarkably effective technique for separating grains or flakes of metal from the gravel accompanying them and we shall see below its very skilful use for assaying tin concentrates. On the other hand, the technique is more effective for some metals than for others. For example, the specific gravity of gold is almost three times that of cassiterite, making its panning easier and more efficient. At Ko-chiu, panning tended to be the preferred method for concentrating relatively rich ores.[22]

A quite different method was frequently used for poorer ores, especially from opencast workings. W. F. Collins provides a good description:

> At the approach of the rainy season, the grass is rooted from the surface in favourable places and the ore-bearing ground is carried to the sides of reservoirs connected by means of canals with washing floors at lower points, sometimes a mile distant on the steep hill-side.[23] When the reservoirs are filled by the rains, the ore is thrown in, and when a consistency of sludge is reached, the contents of the reservoir are allowed to pass into the canal.[24] On the way down, water from the other reservoirs is allowed to pass into the canal so as to assist the 'run.' Somewhere near the washing-floors the 'run' of ore passes into a series of short, parallel-walled, canal-like ponds arranged grid-wise. A considerable quantity of fresh water is here run in so that the tin-stone [cassiterite] sinks in the diluted sludge and the light waste can be run off with the water.[25]

This is the method that was called at Ko-chiu *chhung khuang chien* 沖壙尖 and which can be described as ground sluicing. Collins omits, however, a major point. As the ore sludge was washed down the channels (sluices; the Chinese term was *lung kou* 龍溝) cut into the mountainside, a certain amount of concentrated ore was deposited *en route* in a process duplicating nature's method of creating alluvial deposits.[26] This ore would be periodically shovelled out of the sluices and assembled for the next step in the concentration process.[27]

[22] Collins (1909–1910), p. 190.

[23] Reservoirs were extensively used at Ko-chiu to maximise the amount of rainwater, the only significant source of water in that area, that could be harnessed for mining operations. Depending on the terrain, reservoirs could be up to 3 li or a mile in length; Huang Chu-hsun (*1930*), p. 55. The ditchworks to the washing floors below might actually be as much as several miles long; Su Ju-chiang (*1942*), p. 22.

[24] This is reminiscent of a native method used in Yunnan as early as the +9th century in which pits were dug to collect gold-containing alluvium during the rainy season. Cf. Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 268 and Yoshida (*1967*), pp. 236–7.

[25] Collins (1909–1910), p. 191.

[26] Controlling the amount of water introduced into the sludge was a crucial skill for controlling the flow and, presumably, optimising the deposit of ore in the process; Su Ju-chiang (*1942*), p. 31.

[27] This is essentially the same process described by Agricola in his seventh and eighth methods for washing tin; Hoover & Hoover (1912), pp. 346–7, with two illustrations.

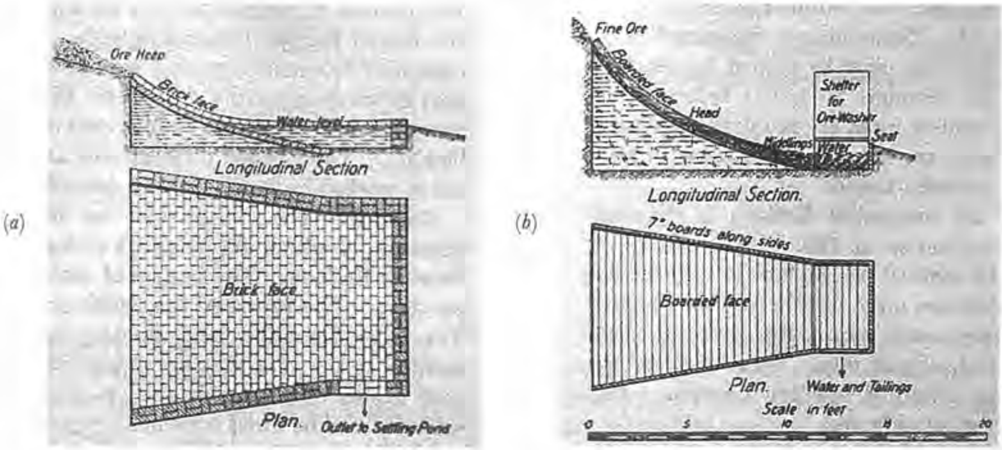


Fig. 112. Buddles for concentrating tin at Ko-chiu. The buddle at the left (*a*), faced with brick, was used in a first washing process that produced coarse and fine concentrate. The wooden buddle on the right (*b*) was used to further concentrate the fine concentrate from the first process. Although buddles at Ko-chiu varied in size and the inclination of their faces, all were of this same basic design, seemingly unique to this area. Collins (1909–1910), p. 191.

The next process for treating the concentrates obtained either by panning or settling involved the use of inclined troughs, called buddles or, from Mexican mining practice, planillas. These buddles differed widely in size, in the inclinations of their faces and and in the materials from which they were made (brick, stone or wood).[28] Collins describes the buddles he saw at the beginning of this century as being generally of two kinds. The first (Fig. 112(*a*) and Fig. 113) was made of brick and used for coarse ore. It had an incline of about 20°.[29] One load for this buddle usually consisted of about 2,500 *chin* or one-and-a-half tonnes of ore.[30] This ore was mixed with water to form a thin pulp, and two men on either side of the buddle agitated the pulp with wooden or iron rakes. The pebbles were raked up to the back (top) of the buddle. This gravel concentrate (*hui men sha* 匯悶砂), generally a relatively rich ore,[31] was then put through one or more washings for further removal of matrix materials. The gravels were also separated by size using sieves. Depending on the quality of the ore, anywhere from 500 to well under 100 *chin* of concentrate might ultimately be obtained.[32]

[28] For some examples, with their names, dimensions and methods of use, see Su Ju-chiang (*1942*), pp. 33–4. They differed from sluices in being much larger, permanently installed, and usually having a curved trough.

[29] Draper (1931), p. 185. [30] Su Ju-chiang (*1942*), pp. 31, 33–4.

[31] Collins (1909–1910), pp. 191–2; Su Ju-chiang (*1942*), p. 33.

[32] Su Ju-chiang (*1942*), p. 31; Draper (1931), p. 185. Identifying the quality of ores was one of the more important and highly developed skills among the miners. Su lists ten qualities of ores, each with its own name and expected production of concentrate. For a similar breakdown of copper ores in Yunnan, based on Wu Chhi-chün's *Tien-nan Khuang-Chhang Thu Lueh* (Wu Chhi-chün (*1845*)), see Chhen Lü-fan *et al.* (*1980*), p. 37. In Yin-chheng, Shansi, coal miners showed a similar ability to make fine distinctions in the quality of different coals, identifying some nine or ten different coal series and claiming to be able to determine *easily* what seam a particular specimen came from; Shockley (1904), p. 851.

Fig. 113. Miners using buddles to concentrate tin ore at Ko-chiu in the 1930s or 1940s. Anon. (1944), Vol. 3, pl. 39.

Fine ores, by contrast, were treated in a buddle with a somewhat more steeply inclined wooden face, up to 45° (Fig. 112(*b*)).[33] Gradually drawing the ore down over the face, the dresser, seated cross-legged on the seat provided, would throw small amounts of water over it. In this way, a hard bed of concentrates would form, with the richest concentrates at the top, followed by poorer ore in middlings and tailings.

Buddles are still in use in Ko-chiu on a small scale. The buddles today are made of concrete and typically there are several in a row (Fig. 114). Where running water is available, hoses are used to spray the ore, obviating the need for a pool of water at the foot of the buddle. It appears that this process can at best produce a concentrate consisting of about 20 per cent tin.[34]

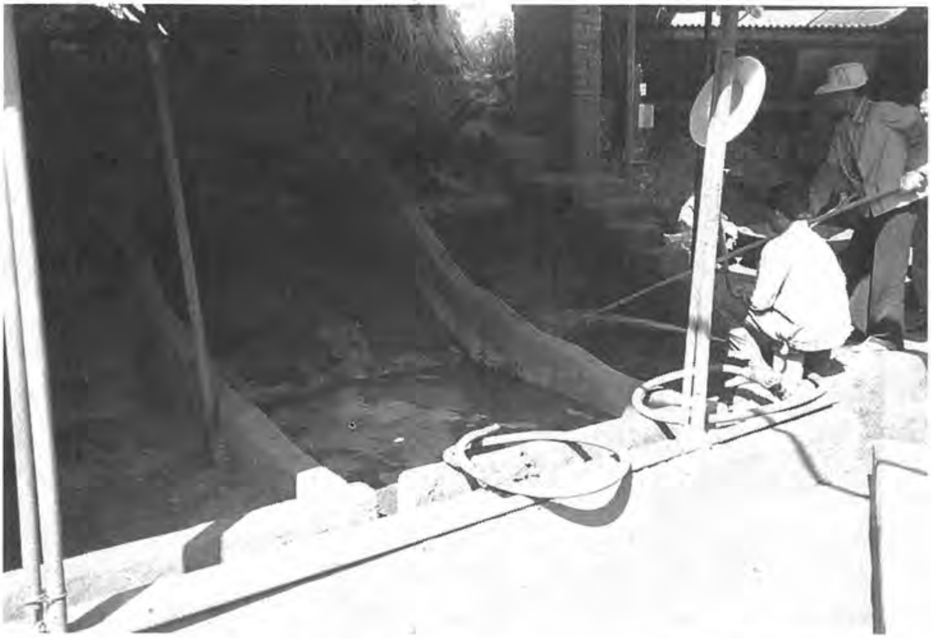
To increase the amount of tin in the concentrate, miners often had recourse to another process making use of large, circular iron pans up to 1.5 m in diameter and 30 cm deep (Fig. 115). The earlier concentrate would be thoroughly stirred in these pans and then a differential settlement would be effected by tapping the sides of the pans with a mallet or a pair of pounding sticks.[35] This process too is still in

[33] Draper (1931), p. 185.

[34] Information provided by Li Yu-chhun, a mining engineer who worked at Ko-chiu for over 40 years. I am very grateful to Mr. Li for arranging my inspection of these processes and for providing me with a great deal of information on Ko-chiu tin mining.

[35] Collins (1909–1910), p. 192.

(*a*)



(*b*)

Fig. 114. Photo (*a*) shows buddles at the headquarters of the Ko-chiu Geological Team (*Ko-chiu ti chih tui* 箇舊地質隊) where a small amount of tin concentrating (of ore brought in by truck from some distance away) was being carried on in 1990 to provide revenue for the work of the team and also work for some people from the surrounding rural area. Photo (*b*) shows buddles (somewhat longer and with a less steep angle) at New Cap Village (Hsin kuan tshun 新冠村), formerly known as Bullshit Slope (Niu shih pho 牛屎破), where the villagers mine and concentrate tin as a side-employment. Original photos, 1990.

(a)

(b)

Fig. 115. Pan method of producing a higher concentrate. A mixture of lower concentrate is agitated in a large pan by pounding the side of the pan with either a mallet (*a*) or a pair of pounding sticks (*b*). The higher concentrate forms on the bottom and may contain up to about 40% tin. Original photo, 1990.

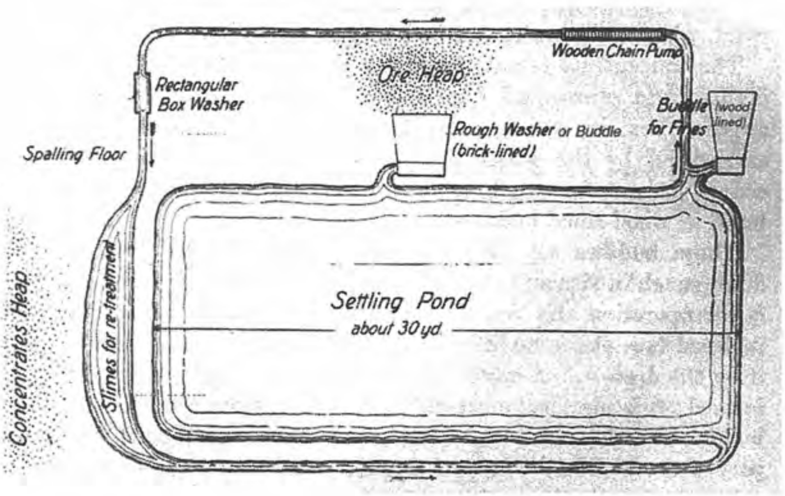


Fig. 116. Concentrating tin ore by washing. Ko-chiu, Yunnan. Concentrating works used recycled water. Note the two buddles, one lined with brick and the second made of wood. Screening was also sometimes used in the concentration process. Collins (1909–1910), p. 191.

use at Ko-chiu and can bring the amount of tin in the concentrate up to about 40 per cent.[36]

Collins provides a drawing (Fig. 116) of a typical washing installation at the beginning of this century. It includes a buddle for coarse ores ('rough washer') and a buddle for fine ores set up next to the settling pond, together with a square-pallet chain-pump to keep the water and slimes circulating.

(3) Characteristics of Traditional Ore Dressing

As the example of Ko-chiu makes clear, traditional ore dressing was able to absorb large amounts of the cheap labour available in China. In general, traditional techniques, no matter how carefully employed, could not remove all the waste or recover all of the ore.[37] Hence, there was always the temptation where labour was cheap, as it usually was, to repeat processes yet one more time in order to get a still higher concentrate or to recover even quite small amounts of ore that would otherwise be lost in the tailings.[38] Still, even when the Ko-chiu tin ores passed through repeated processing in a total effort that might involve as many as 70 dressers before the ore was bagged for delivery to the smelters,[39] the miners found it very difficult to

[36] Draper (1931, p. 185) says up to 50–55% tin.

[37] At Ko-chiu, lead in the concentrates from placer deposits sometimes made them unsaleable because of the problems the lead caused in smelting; Draper (1931), p. 186.

[38] Even slag from smelters was often collected and dressed for the metal it might still contain.

[39] Collins (1909–1910), p. 192; Draper (1931), p. 185.

produce a concentrate of sufficiently good consistency to satisfy the smelters. As late as the 1920s, the tin content of dressed ore delivered to the smelters in Ko-chiu could be as low 35 per cent, with typical fineness only between 45 and 50 per cent.[40] The result was that the smelters in the city, if they wished to produce a tin of high purity, had to maintain their own dressing facilities to rework further much of the ore that they purchased from the miners.[41]

To be sure, there were cases where traditional ore dressing techniques made such effective use of skilled or semi-skilled labour that, even apart from the costs of machinery, there was little if anything to be gained by mechanisation. Bohuslav Stočes, in his mining manual first published in English in 1954, comments in regard to hand sorting and picking: '. . . a great quantity of ore can be picked per day. Whole railway trucks can be filled by one worker. This is therefore a cheap dressing method, though to the layman it looks very unmechanised; sometimes such hand work is better and cheaper than mechanisation.'[42] But hand dressing had advantages that went beyond the picking and sorting stage, particularly with certain kinds of ores. For example, where the ore was present in very fine particles (as with much of the cassiterite at Ko-chiu), mechanical processing tended to be difficult and inefficient at least until flotation processes became the norm – which happened even in the West only in this century.[43]

It should also be noted that ore dressers, through long experience, sometimes developed a level of skill difficult for the layman to comprehend. Even at Ko-chiu today, a skilled washer/assayer can place a handful of concentrate in an assay bowl (Fig. 117(*a*)), mix it with some water (Fig. 117(*b*)), swirl the mixture while allowing lighter material to run off (Fig. 117(*c*)) and then, by observing the amount of tin collected on the outer edge of the concentrate (Fig. 117(*d*)), estimate even to an accuracy of within 1 per cent how much tin is contained in the concentrate.[44] Here is how Lu Jung describes a similar process, this time involving silver ore, in his +1475 *Shu Yuan Tsa Chi*:[45]

No matter how much the ore, on excavation it is pounded by pedal tilt-hammers[46] until it becomes a very fine powder called 'ore powder' (*khuang mo* 礦末). After that, a large bucket is filled with water and the ore powder. This mixture is agitated several hundred times in a

[40] Anon. (1926), p. 155; Torgasheff (1930), p. 212.

[41] Su Ju-chiang (*1942*), p. 36. Kellenbenz (1974, p. 203) claims that, in general, the limitations of traditional smelting techniques placed greater requirements on the preparation of ores for smelting than would often be the case later. Donald Wagner (personal communication) questions this, suggesting that the reverse could very well be true, namely, that the limitations of traditional ore dressing methods made greater demands on the smelting processes.

[42] Stočes (1958), Vol. 1, p. 581. [43] *Ibid.*, pp. 582, 588.

[44] In this demonstration, which took place at the headquarters of the Ko-chiu Geological Team (Ko-chiu ti-chih tui 箇舊地質隊), I had overheard the older of the two women who were pounding the iron pan from which this concentrate was taken say to the other that the concentrating was not yet finished. Given that the finished concentrate could be expected to be in the 40% tin range, the estimate of 34% appeared reasonable. Slessor (1927, p. 96) also remarked that the 'Chinese are very expert in judging the quality of the concentrate by the eye alone.'

[45] Ch. 14, pp. 9a–b. [46] I.e., stamps; see Vol. 4, pt. 2, pp. 183–4.

(a)

(b)

Fig. 117. Assaying the tin content of a concentrate. (*a*) A handful of concentrate is placed in the assay bowl. (*b*) Some water is added.

(c)

(d)

Fig. 117. Assaying the tin content of a concentrate. (*c*) The concentrate and water are swirled, allowing lighter material to flow off, until a tongue forms on the far side of the concentrate. (*d*) By observing the amount of tin collected in the tongue, an estimate can be made of the percentage of tin in the concentrate; in this case, the estimate was 34% Original photos, 1990.

process called 'agitating the mud' (*chiao chan* 攪粘). The mixture in the bucket separates into three parts: that which floats on top of the water, called 'fine mud' (*hsi chan* 細粘); that which remains suspended in the water, called 'plum sand' (*mei sha* 梅砂); and that which sinks to the bottom, called 'coarse orebody' (*tshu khuang jou* 粗礦肉). The fine mud and plum sand are washed in a washing box with a pointed bottom (*chien ti thao phen* 尖底淘盆)[47] so that the gangue (*tshu* 粗) is allowed to float off over the edge of the box while what remains in the box is the concentrate (*ching ying* 精英). The coarse orebody is washed in the same way in a wooden pan shaped like a small boat.[48] Essentially, the purpose is to get rid of the rock (gangue) particles and preserve the real ore. This is then stirred in a bucket. Glittering flecks like stars will be seen. This is called 'orebody' (*khuang jou* 礦肉).

The advantages that came from developing such skills to a maximum led some miners to specialise solely in ore concentration. At Ko-chiu, for example, there were the 'buy ore mines' (*mai khuang chien* 買壙尖) where miners bought raw ore, concentrated it, and then sold the concentrate (*hung* 硔).[49]

Nevertheless, even the highest development of labour skills still left abundant opportunities for improving tools and machines in order to make ore dressing more efficient or effective. Even a cursory examination of Agricola's extensive description of ore dressing in Book VIII of *De Re Metallica* arouses one's admiration for the extreme ingenuity central European miners of the +16th century expended on even very modest improvements to basically simple traditional techniques. To take just one example: the use of sluices for washing ores and metals relies in part, as we have seen, on their having indentations or obstructions to help trap the heavier particles. Agricola describes for us an astounding variety of indentations and obstructions, including several kinds of 'pockets' that might be carved or burned into the sluice planks, that might be round or square, that might be as large as eggs or as little as 2 cm across. Obviously, there was something of an obsession for experimentation at work here that continued until the miners were satisfied that they had found the very best way for washing a certain kind of metal-bearing sand or a particular ore.

China seems to present a contrast here. Admittedly, we are greatly hampered in assessing traditional ore dressing techniques (as well as all the other aspects of mining) by a paucity of evidence and the still preliminary state of the analysis to which that evidence has been subjected. But insofar as our present knowledge permits generalisation, it appears that nothing like the degree of inventiveness Agricola describes was to be found at pre-20th century Chinese mining sites, large or small. If this is indeed true, it calls for explanation, given the considerable ingenuity one finds in other areas of traditional Chinese technology (including metallurgy). Could part of the reason be that Chinese miners, generally relegated to so much lower a status than most miners in early modern Europe, were correspondingly less inclined

[47] See Fig. 31. [48] See Fig. 30(*b*). [49] Chhen Lü-fan *et al.* (*1979*), p. 3, fn. 2.

Fig. 118. An overshot waterwheel powering a pair of tilt-hammer stamps for crushing galena at a lead mine in southwest Yunnan. Brown (1923), pl. 5. (Compare *TKKW*, ch. 4, p. 88, reproduced in Vol. 4, pt. 2, Fig. 617.) As noted in Vol. 4, pt. 2, pp. 392ff, the Chinese used recumbant stamps only, and not the vertically acting type so prominent in late medieval and early modern mining in Europe. (Hoover & Hoover (1912), pp. 284–7, and 299 for some examples.) The Chinese horizontal installations may have had two advantages: (1) permitting a heavier installation, much to be valued when crushing rock; and (2) cheaper construction and maintenance.

to take pride in their profession *and in their work*? Did this lead to correspondingly less interest in ways to do their work better?

One also finds in Agricola the same passion for improvements in that area of ore dressing most susceptible of mechanisation in traditional times, i.e., crushing and milling.[50] To be sure, where economic conditions made it possible, Chinese miners made use especially of waterwheels to power tilt-hammer stamps, usually two stamps to a wheel (Fig. 118). Such waterwheel-powered wet stamping operations are to be seen in China even today, their machinery still almost entirely made of wood (Fig. 119).[51] Striking, however, is the very primitive nature of the machinery and its operations which incorporate few if any of the many improvements that were being applied at the +16th century mines described by Agricola. Here, cost was undoubtedly a major factor. No significant advances in the application of mechanisation could occur without the kind of capital investment that was rarely to be seen in Chinese mining.

[50] Hoover & Hoover (1912), pp. 267–351. See also Ludwig (1978), pp. 150–5.

[51] Wet stamping was a major improvement over dry stamping in that it limited the loss of metal through pulverisation; Kellenbenz (1974), pp. 203–4; Ludwig (1979), pp. 77ff.; Vogel (1991c), p. 78. It seems to have been invented at Schwaz in the Tirol in Austria, the largest mining operation in Europe in the early +16th century, some time around +1512; Ludwig (1978), p. 152; Ludwig (1979), p. 77. We do not know when it was first used in China.

(a)

(b)

(c)

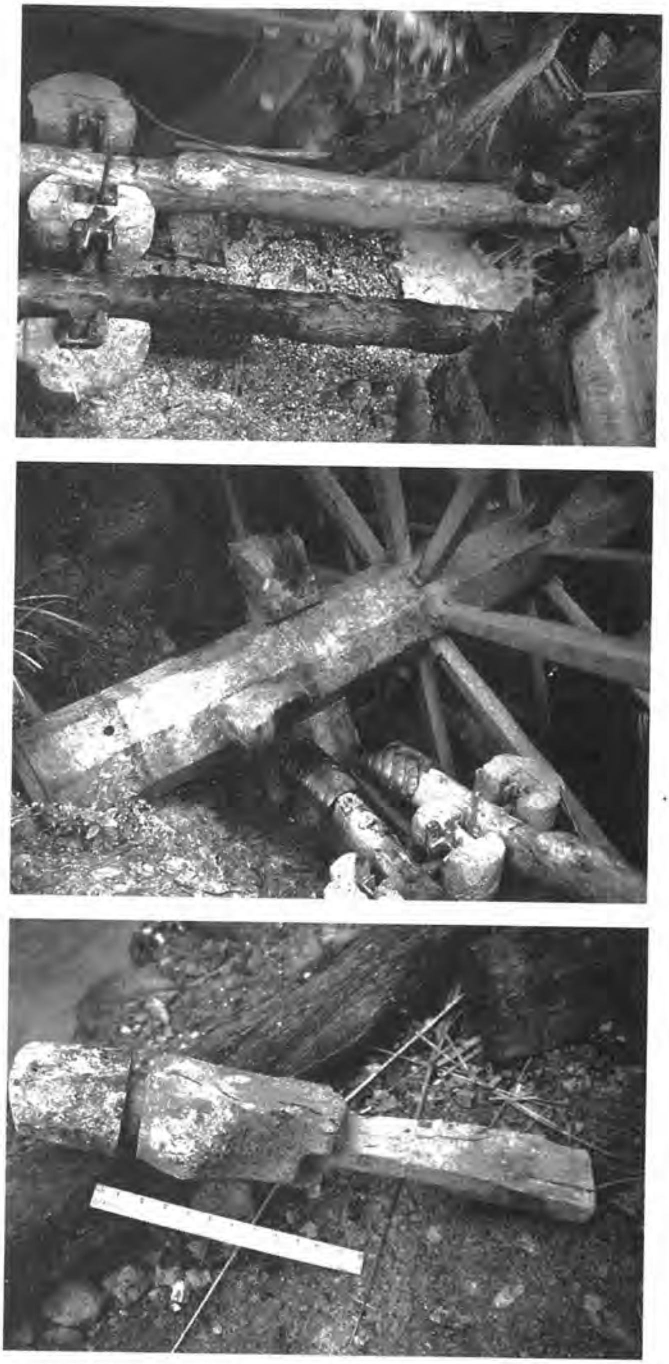


Fig. 119. Details of a waterwheel powering a pair of stamps at a gold mine in Thao-hua 桃花, Kwangsi. With the exception of (*a*) the pivot and its housing, (*b*) reinforcing plates and the end of the stamp arms where they come into contact with the cams on the extended axle of the waterwheel, and (*c*) metal heads on the stamps, the entire machinery was made of wood. (This was one of about a dozen waterwheels still in operation at this mine.)
Original photos, 1994. Brown (1923, p. 133) found this to be a 'rough but none the less useful machine.'

(j) THE COPPER PRECIPITATION PROCESS

The copper precipitation process, sometimes referred to as the wet copper or vitriol copper or copper cementation process, occupies a unique place in the history of Chinese mining.[1] As a production technique that made use of chemical reactions but not heat to separate copper in solution from unwanted accompanying materials, it lies on the border between ore dressing, which can be seen as the final step in mining, and metallurgy, in which heat plays a prominent rôle. The application of this process on an industrial scale in the +11th and +12th centuries opened up new sources of copper that at least for a time provided a significant supplement to the declining output of previously rich copper deposits. By +1105, about 660 tonnes or some 18 per cent of China's recorded copper production came from this source.[2] Ten years later, at what seems to have been the peak of vitriol copper production in traditional China,[3] 1,200 tonnes or some 26 per cent of copper production at that time came from this source.[4] In the mid-+1160s, vitriol copper output had shrunk to 140 tonnes annually, a figure that nevertheless accounted for 80 per cent of a much shrunken recorded production![5]

(1) PRECONDITIONS

The nature of copper deposits assures that their associated waters and earth will typically contain a certain amount of disseminated copper. Most copper deposits originate as hydrothermal depositions of copper iron sulphides (bornite and chalcopyrite) (Fig. 120). Since the copper sulphides are highly unstable, those relatively close to the surface of the earth are easily oxidised over time by the action of water, air and ferric salts in solution, and are transformed into carbonates (malachite and azurite), oxides (cuprite and tenorite), and sulphates (brochantite and chalcanthite).[6] These so-called secondary deposits are very soluble and are ordinarily leached out of the upper levels of a copper deposit, leading to the formation of an enriched oxidised ore zone between the leached-out upper levels and the water table.[7] This enriched oxidised zone can contain both earthy matter impregnated with

[1] I have previously dealt with this topic more briefly in Golas (1995).

[2] *Chhün Shu Khao Suo, hou-chi*, ch. 60, cited in Nakajima (*1940*), p. 409 along with several other texts relating to these figures.

[3] *Wei Thai-phu Wen Chi*, ch. 10, p. 12a, and discussion of post-Sung developments below.

[4] Nakajima (*1940*), pp. 410–12.

[5] *Ibid.* These figures refer only to south China (actually, about two-thirds of the territory of the Northern Sung), the region more or less under control of the Sung government from +1127 onwards. This area included, however, all of China's major copper-production sites in that period.

[6] Cf. Table 6 above. Deposits of native copper can also be produced by the precipitation process we are considering here; Searle (1938), p. 55.

[7] Tylecote (1992), p. 10; Rosenfield (1965), pp. 133–4; Sinkankas (1970) pp. 159–67.

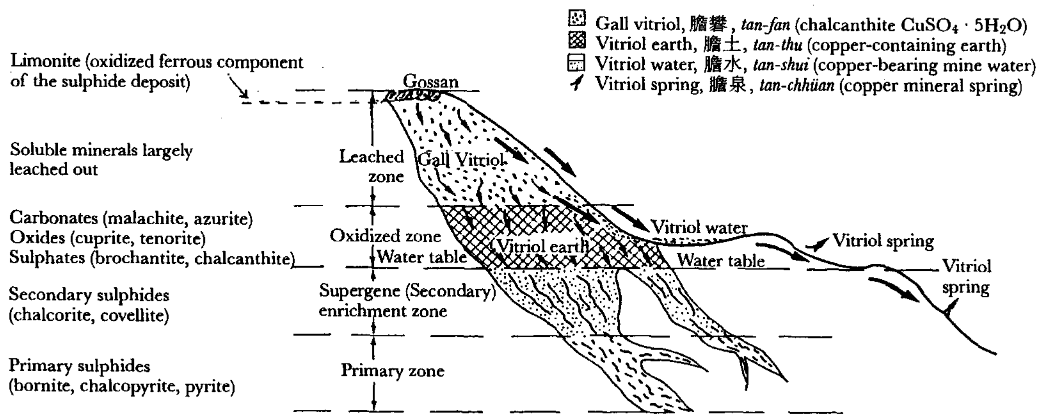


Fig. 120. Vitriol earth and vitriol waters in a typical copper deposit. After Lung Tshun-ni (1986), p. 118 and Rosenfeld (1965), p. 134. Compare Fig. 8 above.

copper (in the traditional terminology, 'vitriol earth' *tan thu* 膽土 or *thu lü* 土綠[8]) as well as copper-bearing mine waters (variously called 'vitriol waters' *tan shui* 膽水, 'alum waters' *fan shui* 礬水, 'vitriol alum waters' *tan fan shui* 膽礬水 or 'yellow alum waters' *huang fan shui* 黃礬水).[9] There was no way in traditional times to extract the finely disseminated copper directly from vitriol earth. By leaching the vitriol-containing earth, however, what the Chinese called the 'leach copper' (*lin thung* 淋銅) method, miners obtained vitriol water that could then be dealt with in the same way as naturally occurring vitriol water.[10] It was vitriol water, then, that offered a potentially new source of copper, sometimes even where economical ore deposits had been exhausted. The detection of this potential and the working out of techniques for extracting significant quantitites of copper from vitriol waters constitute a major achievement of traditional Chinese mining.[11]

Efforts to extract copper from vitriol waters had to be preceded by a recognition that there was indeed something special about these waters. That recognition was not difficult to come by, at least in certain circumstances. Colour was a major clue. Just as miners were drawn to the striking green and blue tones of rocks containing malachite and azurite, so too vitriol waters often announce themselves by staining the rocks over which they flow a vivid blue-green or dark red colour.[12] In addition, the colour of the water itself, its bitter taste or foul smell, its inability to support aquatic life could all have served as clues that there was something worth investigating here.[13]

Possibly as early as the Thang, if not earlier, alchemists or others had learned that boiling this water until it had all vaporised left behind a powder that came to be called *tan fan* 膽礬, now referred to as copper sulphate, blue vitriol or chalcanthite. If this powder was then heated to a high enough temperature, it became metallic copper. The evidence that such experimenting was actually going on by the Thang is sketchy. Kuo Cheng-I cites a text from the Thang work *Tan Fang Ching Yuan* 膽房鏡源 (The Mirror of the Alchemical Elaboratory; a Source-book) referring to

[8] Kuo Cheng-i (*1981*), p. 68. [9] Chang Hung-chao (*1954*), p. 33.

[10] *Chhing Po Tsa Chih*, cited in *MCPT*, ch. 25, p. 793; *TSFYCY*, ch. 85, p. 28a; Chang Hung-chao (*1954*), p. 33; Lung Tshun-ni (*1986*), p. 150; Nakajima (*1940*), pp. 401–2. Kuo Cheng-i notes a passage in the 'Ta Yeh Fu' 大冶賦 of Hung Tzu-khuei 洪咨夔 (*chin-shih*, +1208) that shows that this term could also refer to a process whereby low-grade sulphide ores were excavated and exposed to weathering which produced solid egg-yoke yellow clumps of vitriol that were then ground and, presumably, added to water to make it vitriol water; *Phing Chai Wen Chi*, ch. 1, p. 5b; Kuo Cheng-i (*1983*), pp. 60–1. *Lin thung* was shorthand for 'soaking iron to produce copper' (*lin thieh chheng thung* 淋鐵成銅).

[11] In modern chemical terminology, this is a hydrometallurgical cementation or precipitation process. As Lung Tshun-ni notes: '"Cementation" is the term used in hydrometallurgy to describe the electro-chemical precipitation of a metal from a solution of its salts on a more electropositive metal.' Lung Tshun Ni (1986), p. 113. A common modern industrial application of the cementation process is the use of zinc dust to precipitate gold and silver from cyanide solutions.

[12] Yen Yü (*1957*), p. 69. This was brought home to me when I witnessed the phenomenon at Chin-kua-shih (金瓜石) in northern Taiwan in the summer of 1988; the bright blue-green of the stained rocks was easily the most striking characteristic of the entire landscape. My guide on this trip was Mr. Lung Tshun-ni, who has provided invaluable help to me at a number of points in this study.

[13] *MCPT*, ch. 25, pp. 792–4. Skilled miners later were even able to distinguish the quality of vitriol waters for precipitating copper by observing their colour, smell and taste. Blue-green, pungent and bitter (*chhing se khu* 青澀苦) waters were supposedly best, followed by yellow-brown, vinegary (*huang hsi suan* 黃醯酸) waters; *Phing Chai Wen Chi*, ch. 1, pp. 4b–5a; Kuo Cheng-i (*1983*), p. 60. For much information on what European miners noticed about vitrol waters in the +17th century and tests on different waters, see Searle (1938), chapter III *passim*.

such a process but Chao Khuang-hua and his fellow researchers make a good case that the text cited is a later addition.[14] The *Lung Hu Huan Tan Chueh* 龍虎還丹訣 (Explanation of the Dragon-and-Tiger Cyclically Transformed Elixir), that some would date to the middle of the +8th century,[15] has a number of passages referring to the boiling of vitriol water in an iron cauldron to produce 'red silver' (*chhih yin* 赤銀), i.e., pure copper. Kuo Cheng-I interprets the process as a kind of combination of precipitation and amalgamation where mercury in the water would immediately trap the copper ions released through precipitation so that a mercury/copper amalgam would form, after which heating volatilised the mercury, leaving behind the pure copper.[16] In his *Pen Tshao Kang Mu* 本草綱目 (*PTKM*),[17] Li Shih-chen 李時珍 cites a text from the *[Hsien Yuan] Pao Tshang [Chhang Wei] Lun* 軒轅寶藏暢微論 (The Yellow Emperor's Discourse on the [Contents of the] Precious Treasury [of the Earth]), a work completed in +918 and perhaps containing materials from the Thang, which may refer to a boiling-followed-by-refining process to produce copper, though the text is almost certainly corrupt. But even if the surviving texts are far from conclusive, there is nothing inherently improbable about the possibility of such experiments having been carried on in the Thang, or even earlier.

The *Pao Tshang Lun* (Discourse on the Precious Treasury), in a passage that may be Thang or earlier, also introduces the term 'iron copper' (*thieh thung* 鐵銅),[18] and this is interesting because it suggests another discovery that was necessary before any substantial amounts of copper could be derived from vitriol waters. Even without relying on amalgamation, a process using vitriol water that depended on boiling away the water in order to get the small residue of copper powder had no chance, because of fuel costs, of ever being used on anything but a very small scale for experimental or other special purposes.[19] There was a potential alternative process, however. It would make use of the fact that copper lies near the end of the electrochemical series and can therefore easily be displaced from salt solutions by a metal such as iron.[20]

Some Chinese from at least Han times onward had begun to notice the effects of this kind of reaction. The extensive mining of copper since the Shang together with availability of iron or iron-tipped tools from the beginning of the Warring States period provided abundant opportunities for Chinese miners to observe the transformation that took place in iron when it came into contact with copper salts.[21] Pharmacologists and alchemists in their laboratories noted the same reaction. In the Chhin or early Han *Huai-nan Wan Pi Shu* 淮南萬畢術 (The Ten Thousand

[14] Kuo Cheng-i (*1981*), p. 67; Chao Khuang-hua *et al.* (*1986a*), p. 327. [15] Kuo Cheng-i (*1981*), p. 68.

[16] Kuo Cheng-i (*1981*), p. 68; Kuo Cheng-i (*1983*), p. 59. The use of mercury would make this amalgamation process, apart from its difficulty, far too expensive for obtaining copper on any scale, but it did have the advantage of producing a purer copper than was ordinarily obtained from simpler and less costly methods, making its refining easier.

[17] *PTKM*, ch. 8, p. 8. [18] Yang Ken (*1980*), p. 2.

[19] Hartwell, perhaps misled by Shen Kua, failed to realise this; Hartwell (1962), p. 156.

[20] Vol. 5, pt. 2, pp. 245–6.

[21] The frequent association of iron and copper deposits was also familiar to early Chinese miners and may have encouraged them to be alert to a special relationship between the two metals; Wu Tzu-chen (*1958*), p. 2.

Infallible Arts of (the Prince of) Huai-nan), we read: 'When azurite (*pai chhing* 白青) contacts iron (*te thieh* 得鐵), the iron turns into copper.'[22] Similarly, the *Shen Nung Pen Tshao Ching* 神農本草經 (Classic of Pharmaceutics of the Heavenly Husbandman), dating in its final form (now lost, but much quoted in later pharmaceutical works) to about the +2nd centrury, has: '*Shih tan* 石膽 can turn iron into copper (*neng hua thieh wei thung* 能化鐵為銅).'[23] Although very laconic, these statements are more precise in their reference to salts of copper than the slightly later reference to the same reaction by Pliny.[24]

Several more references to this reaction have survived from the period between the Han and the Sung. Ko Hung 葛洪, writing about +300, distinguishes what he sees as true transformations, such as when cinnabar is transmuted into gold, from 'counterfeit' (*cha* 詐) transformations, as when iron is rubbed with malachite. In the latter case, the change occurs on the outside but not on the inside; i.e., the copper is no more than a coating on the iron.[25] Thao Hung-ching, the great Taoist physician and alchemist (+452 to +536), was even more explicit on this in his *Pen Tshao Ching Chi Chu* 本草經集注 (Collected Commentaries on the *Classic of Pharmaceutics of the Heavenly Husbandman*) where he denotes the rubbing of iron with a mixture of 'bird droppings alum' (*chi shih fan* 雞屎礬), vinegar and refined copper as 'plating' (*thu* 塗).[26] Not long after, or perhaps even earlier than Thao's comment, the *San Shih Liu Shui Fa* 三十六水法 (Thirty-six Methods for Bringing Solids into Aqueous Solution) provides a very detailed description of how to concoct an aqueous solution of *fan shih* 礬石 for rubbing on iron to induce this reaction.[27]

[22] Nakajima (*1941*), pp. 499–503; Lung Tshun Ni (1986), p. 114, slightly modified; cf. also Vol. 5, pt. 4, p. 202. *Pai chhing* (lit. 'white or pale green') indicates a weathered blue-greenish material, probably the basic copper carbonate, azurite (Vol. 5, pt. 2, p. 166, no. 23) where its colour has been paled by efflorescence; Lung Tshun-ni (*1986*), p. 141.

[23] Nakajima (*1941*), pp. 497–9; Lung Tshun Ni (1986), p. 114. *Shih tan* 'stone gall', just as *tan fan* above, is chalcanthite (hydrated copper sulphate) or blue vitriol. Chalcanthite was so-called because it resembled the gallbladder in its bitter and astringent taste as well as sometimes in its colour; Lung Tshun-ni (*1986*), p. 141. For another possible reference to this reaction in the entry for malachite (*khung-chhing* 空青), cf. Vol. 5, pt. 4, p. 202, fn. (n).

[24] Cf. Vol. 5, pt. 4, p. 202, fn. (n).

[25] For a translation of the full passage, cf. Vol. 5, pt. 3, p. 104; cf. also Vol. 5, pt. 4, pp. 202–3. Ko Hung tells us specifically that if one 'uses malachite (or azurite) to coat (smear) iron, the iron [will acquire] a red colour like that of copper (*i tseng-chhing thu thieh, thieh chhih se ru thung* 以曾青塗鐵鐵赤色如銅).' The statement in Vol. 5, pt. 2, p. 67 that this clearly refers to the wet copper process is probably incorrect. The coating that forms in the wet copper or precipitation process is in appearance typically like a rust and not like the metallic surface that seems to be called for in this context. Cf. however the puzzling passage in Emmanuel Swedenborg's very important *Treatise on Copper* which suggests that miners in Falun determined that 'certain rust of a reddish-brown colour' deposited by precipitation was *not* copper; Searle (1938), p. 51. Immediately afterwards, a copper deposit by precipitation is referred to as a 'crust'.

[26] Vol. 5, pt. 3, pp. 129–30; Lung Tshun Ni (1986), p. 115. Lung Tshun-ni takes the *chi shih fan* to be some kind of copper mineral. The same term may sometimes be used to designate a ferrous sulphate (melanterite, green vitriol, copperas); cf. Vol. 5, pt. 2, p. 172, no. 77. Presumably, it would not need to be a copper mineral since refined copper is added to the solution. Note that Thao does not seem aware that it is really the copper that causes the colouring of the iron.

[27] The *San Shih Liu Shui Fa* is a pre-Thang work included in the *Tao Tsang* which could date at least in part from as early as the Western Han; cf. above, Vol. 5, pt. 4, p. 169; Chhen Kuo-fu (*1982*), pp. 315–16. See also Lung Tshun Ni (1986), p. 115, which would place the work tentatively in the Eastern Han. The text makes sense if we follow Lung in taking the *fan shih* here to be not a reference to alum, as is normally the case, but to a copper-bearing iron sulphate mineral; cf. Vol. 5, pt. 4, p. 201; pt. 2, p. 246. For Lung's translation, cf. Lung Tshun Ni (1986), p. 115.

We are now back at the Thang and ready to examine how recognition of the special nature of vitrol waters together with awareness that iron underwent interesting changes in contact with copper became the two key elements in the emergence of the wet copper process. The *Tan Fang Ching Yuan* 膽房鏡源, referred to above, follows its description of the boiling of vitriol waters to obtain a copper powder with the statement: 'The iron cauldron in which the vitriol waters are boiled after a long time also changes into copper (*chu tan fan thieh fu chiu chiu (chih?) i hua wei thung i* 煮膽礬鐵釜久久(之?)亦化為銅矣).'[28] In other words, after the cauldron had been used for a certain period of time to boil vitriol waters, its surface presumably developed a plating of copper, encouraging the belief that these waters could transform iron into copper.[29]

It is not beyond the realm of possibility that some information on what the alchemists were doing was known in mining circles. Yet there is no evidence to suggest that the eventual successful development of a process for obtaining copper from vitriol waters on an industrial scale, finally achieved at the end of the +11th century, had anything to do with those experiments. Rather, the one piece of evidence explicitly referring to the key discovery suggests quite a different stimulus. A story already very old when we find the first reference to it in Chou Hui 周輝's +1192 work, *Chhing Po Tsa Chih* 清波雜誌 (Miscellaneous Notes [by One Living near the] Chhing-po Gate), tells of a man who lost his (iron) keys in some vitriol water. When he returned to the spot the next day and found the keys, they had turned to copper.[30] Whether this particular story is true or not, it could well have been an experience like this (rather than experiments in the laboratories of alchemists) that alerted miners, especially at copper mines in well-watered south China,[31] that pieces of iron placed in vitriol waters and left there for a time acquired on their surface a coating, often in the form of a dark red powder, which could be scraped off and fired to a high temperature in order to produce metallic copper.[32]

Chou Hui does not tell us when the story of the lost keys is supposed to have taken place. Though some would argue that the wet copper process was already used by miners in the Thang,[33] the evidence for this is far from persuasive. More likely, the

[28] *TT* 595; Kuo Cheng-i (*1981*), p. 67. As Kuo notes, this is the source for the first part of Shen Kua's description of copper cementation in the *MCPT*. The point is important because it shows that Shen derived his information not from actually having witnessed the process or talking to someone who had, but rather from his broad reading. Both Hua Shan and Yen Yü recognised the difficulty of making technological sense out Shen's description; Hua Shan (*1982*), p. 120 and Yen Yü (*1957*), p. 68. They did not realise, however, that Shen was actually drawing on an earlier work. I would like to express my thanks to Mei Jianjun 梅建軍 of Peking University of Science and Technology's Archaeometallurgy Group who generously provided me not only with a copy the Yen article but also of a number of other articles I have used in writing this section.

[29] What actually would have happened could and should be tested by experimentation.

[30] *Chhing Po Tsa Chih*, ch. 3, p. 39b (ch. 12, p. 3b); Vol. 5, pt. 4, p. 204, where the whole passage of which this forms a small part is translated.

[31] Hsia Hsiang-jung *et al.* (*1980*), p. 258.

[32] The appearance of the iron coated with copper powder was sometimes compared with the appearance of rotted wood (*hsiu mu* 朽木); cf. *TSFYCY*, ch. 85, p. 24a; Hsia Hsiang-jung *et al.* (*1980*), p. 255. This analogy probably reinforced the 'common-sense' view of most Chinese observing the process that somehow the iron itself was transformed into copper, a view that was held also, at least for a time, by Isaac Newton; see above, Vol. 5, pt. 2, p. 35, fn. (a).

[33] Wu Tzu-chen (*1958*), p. 3.

crucial developments for at least smaller-scale production using precipitation of copper on pieces of iron occurred after the founding of the Sung, perhaps in the late +10th or early +11th century. The earliest reference to the process in a Sung work may be the entry in the *Thai-phing Huan Yü Chi* 太平寰宇記 (The Universal Geography of the Thai-phing [976–983] Reign-period) that mentions the presence of vitriol water on Chhien Mountain (*Chhien-shan* 鉛山) in Hsin-chou 信州 from which one can make copper by soaking iron in it.[34] There seems to be no further reference to the process until well into the second half of the following century.[35]

(2) The Sung Breakthrough

Once it had been recognised that the reaction between vitriol waters and iron could produce copper, implementation of the wet copper process, most commonly referred to in the texts as the '(vitriol water) steeping copper method' ([*tan shui*] *chin thung fa* [膽水]浸銅法) might seem to have been quite simple (Fig. 121). Certainly the texts describing the process have a straightforward, matter-of-fact ring to them.[36]

First take cast iron (*sheng thieh* 生鐵) and hammer it into thin strips.[37] They will look like the iron used in pots.[38] Place the strips in a vitriol water trough, arranging them like fish scales. Soak them for several days. The iron pieces will be made thinner by the vitriol water and a reddish rust will form on their surface. Collect the rods, scrape off the iron[39] rust, wash it, and fire it in a furnace. Only after it has been refined all of three times will it become copper. The iron that has not been transformed can be added to new iron strips and arranged again in the trough for soaking.[40]

[34] The text is cited in Chhi Hsia (*1987–1988*), Vol. 2, p. 560. It does not seem to appear in my edition of the *Thai-phing Huan Yü Chi.*

[35] Two possible references from the +1030s are both highly suspect. The first concerns a certain Hsu Shen 許申, an official in the Tax Section of the State Finance Commission, who suggested during the Ching-yu 景祐 reign-period (+1034 to +1037) of Emperor Jen-tsung 仁宗 that the government 'use medicines/drugs (= vitriol (?)) to transform iron into copper (*i yao hua thieh chheng thung* 以藥化鐵成銅). *Sung Shih*, ch. 181, p. 4380; *Ibid.*, ch. 299, 9928; *HCP*, ch. 116, p. 2718 [+1035]. Although these texts have been accepted by many scholars as referring to the copper precipitation process, Nakajima Satoshi many years ago argued quite persuasively that this is a garbled tradition and that Hsu was advocating a process intended, through the use of some chemical reaction or other, to make possible the substitution of iron for lead and tin in bronze coins, an effort that failed at the outset because of the difficulty of casting the resulting alloy. (On Hsu Shen, see also Wang Sheng-to (1996), p. 20.) The second episode involves a certain official by the name of Chhien Hsun 錢遜 who had memorialised that the same Chhien Mountain in Hsin-chou produced *shih-lü* 石綠 (ordinarily meaning a copper carbonate) that could be decocted (*pheng lien* 烹煉) to make copper; *HCP*, ch. 120, p. 2837 [+1037]; Chhi Hsia (*1987–1988*), Vol. 2, p. 561. Without either a clear mention of vitriol or any use of iron, it seems most doubtful that this can be taken as a reference to the precipitation process. Finally, a text in the +17th century *Tu Shih Fang Yü Chi Yao* can be read to suggest that officials were involved in implementing a wet copper process in Chhü-chiang hsien 曲江縣 of Shao-chou 韶州 in Kuang-nan east circuit as early as the beginning of the Sung; Yen Yü (*1957*), p. 69. The absence over the next century of any other evidence for successful use of the process in producing copper in quantity argues for a conservative reading of the text, which would leave open the date when the process was first implemented in this area.

[36] The most complete Sung description occurs in *SHY:SH*, ch. 11, p. 3a. Somewhat different (and briefer) versions of this text appear in *Sung Shih*, ch. 180, p. 4394 [+1143?] and *WHTK*, ch. 18, p. 181a.

[37] Because of the hammering, Donald Wagner suggests that the meaning here of *sheng thieh* may not be cast iron but rather some kind of 'crudely smelted iron', for example, from the crucible smelting process; private communication.

[38] Kuo Cheng-i stresses this phrase, contending that it indicates that the iron strips used in the industrial application of copper precipitation evolved from the iron pots earlier used to heat the vitriol solution; Kuo Cheng-i (*1981*), p. 68.

[39] Reading *thie* 鐵 for *chhien* 錢.

[40] Compare Vol. 5, pt. 4, p. 203; Lung Tshun Ni (1986), p. 119.

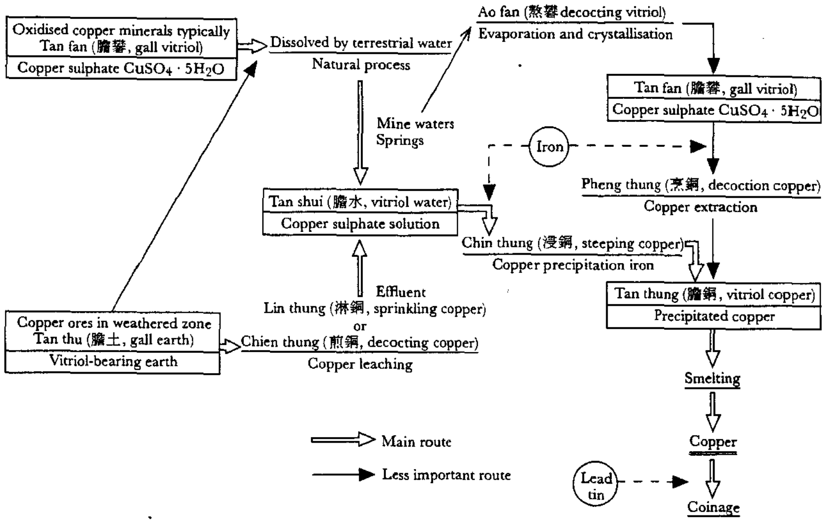


Fig. 121. Flow chart of production and utilisation of precipitated copper in China during the +11th and +12th centuries. Based on Lung Tshun-ni (1986), p. 123.

In fact, the process was much less straightforward than this would suggest. In the first place, as Swedenborg's *Treatise* makes clear, the results obtained from precipitation attempts could vary considerably depending on the copper and other mineral content of the waters, whether the precipitation was attempted in stagnant or flowing waters, the rate of flow in the latter case, and undoubtedly other factors as well.[41] But when it worked, the process had a number of clear advantages. Not needing fuel until the refining step, it could be implemented anywhere the vitriol water and sufficient iron were available.[42] At its simplest, it required no great investment in equipment, and labour costs were low. With a relatively small investment of capital, the efficiency of the procedure could be significantly improved by building holding ponds with sluices and gates to control inflow and outflow of the water. Placing the iron pieces in gently flowing waters fed by these ponds would not only increase the amount of copper precipitated out of the water but would also speed the process.[43]

[41] Searle (1938), chapter 3 *passim*. One set of modern experiments suggests that a minimum of about 3g/l of soluble copper is necessary to produce a high quality metal; Rostoker & Shen (1984), p. 19 and *passim*.

[42] Transporting the copper-containing precipitate for refining, if necessary, would be far easier than transporting ore for smelting.

[43] Thus, Chao Fan (+1143 to +1229) begins his description of the process with the words: 'Dike up a spring to form a pond.' *Chang-chhüan Kao*, ch. 5, cited in Chhi Hsia (*1987–1988*), Vol. 2, p. 561. At Rammelsberg in the Harz mountains during the +17th century, it was generally accepted that 'water corrodes iron better when it is flowing than when stagnant...' and Swedenborg recounts an experiment by Swedish miners in which, after leaving iron in stagnant vitriol waters for 14 days, 'not the smallest amount of copper had been precipitated ...'; Searle (1938), pp. 61; 50–1. (I am thankful to Donald Wagner who drew my attention to this work and provided me with a copy of the chapter on copper precipitation.)

Of course, without the understanding provided by modern chemistry, Chinese miners could never really comprehend what was happening in this process. Thus the +17th century *Tu Shih Fang Yü Chi Yao* 讀史方輿紀要 (The Essentials of Geography for the Reading of History), apparently citing a Sung text describing in detail the wet copper process at Hsin-chou 信州, makes the statement that 'the water [that has been used] and is left over cannot be used again' (*yü shui pu kho tsai yung* 餘水不可再用) but attempts no explanation why this is so.[44] The lack of this kind of understanding, however, did not keep Chinese miners from working out appropriate processes by trial and error. For example, variations in the percentage of copper in different vitriol streams meant that longer or shorter precipitation times had to be determined in order to obtain the maximum of copper powder while still moving the process along as quickly as practicable.[45] Thus, according to Wei Su's 'Preface to the *Essentials of Steeping Copper* (*Chin Thung Yao-Lueh Hsu*)', written in the Yuan, the various springs at Jao-chou 饒州 in the late +11th century were classified according to whether their precipitation period was 5, 7 or 10 days.[46]

Implementation of this process on a significant scale came very slowly. Part of the reason may have been that, because of the nature of the vitriol waters made use of by the Chinese miners, large-scale works could produce only very impure copper containing high levels of iron.[47] Some officials even doubted whether this was 'real' copper (*chen thung* 真銅) equivalent to that produced by smelting.[48] When high levels of iron were present in the minting alloy, they made casting difficult, resulting in coins that were poor both in metallic quality and in appearance.[49] Because of the

[44] *TSFYCY*, ch. 85, p. 28a; Chang Hung-chao (*1954*), p. 33. Investigation of the process employed in Kiangsi in the early 1980s revealed that the vitriol waters contained on average 70–80 mg of copper per *sheng* (litre) though the content could range as high as 200 mg. After precipitation, it had dropped to only about 10 mg; Kuo Cheng-i (*1983*), p. 61. We know that, in the Sung, a single sluice ([*lin thung*] *phen-tshao* 淋銅盆槽) for precipitating copper typically produced on average about 400 *chin* of copper per year; Nakajima (*1940*), pp. 403–4. If the vitriol water processed contained an average of 80 mg of copper per litre, of which 70 mg could be recovered, that would require the processing of some 3,500,000 litres of water yearly.

[45] Here, too, colour was a helpful clue: streams with greater amounts of copper will often be more bluish than greenish, a point noted in +17th century Europe by Joachim Jungius; Pagel (1969), p. 103. I know of no Sung writer, however, who makes this observation.

[46] *Wei Thai-phu Wen Chi*, ch. 10, p. 12a; Lung Tshun-ni (*1986*), p. 149; Hua Shan (*1982*), p. 120; Hsia Hsiang-jung *et al.* (*1980*), p. 255, fn. 1. The work for which this preface was written, the *Chin Thung Yao-Lueh* 浸銅要略 (The Essentials of Steeping Copper), was written in the Shao-sheng 紹聖 period (+1094 to +1097) of the Sung by a certain Chang Chhien 張潛 and was apparently the first manual to describe this process in detail. Unfortunately, it was lost in the Yuan or not long after; Lung Tshun Ni (1986), p. 120. Swedenborg includes precise results from many experiments with precipitation times ranging from 24 hours (for iron the thickness of a knife blade) to half-a-year, but typically measured in weeks and not days, as in the Jao-chou case; Searle (1938), chapter 3, pp. 58, 59 and *passim*. For the copper precipitation process at Te-hsing 德興, Jao-chou, see also Sun I-kang (*1990*), pp. 40–1.

[47] This is certainly not always the case. Even though Swedenborg notes similar problems with certain copper precipitation efforts in +17th century Europe ('the precipitated copper appeared to be defiled, insomuch that it could with difficulty be separated and purified from [impurities it contained] . . .'; Searle (1938), p. 51), at other places it is clear that the process produced copper of extremely high quality, typically very malleable and ductile; *Ibid.*, pp. 52, 56, 57, 58 and 60.

[48] Chao Khuang-hua *et al.* (*1986a*), p. 329. Even as late as the +13th century, the Emperor Li-tsung 理宗 claimed that copper produced by the wet copper process was 'really iron' (*shih thieh erh* 實鐵耳)! *Hsu Wen-Hsien Thung Khao*, ch. 7, p. 2840b; Yen Yü (*1957*), pp. 70–1.

[49] *Sung Shih*, ch. 180, p. 4380. Conceivably, the artisans may even have tried using the copper powder directly without refining it. But it seems clear that, even with repeated refinings, it was difficult to produce top quality copper from the wet copper process. Though the 'Official Sung History' (*Sung Shih*) speaks of three refinings as

difficulty, widely recognised at the time, of producing a good copper–iron alloy, these coins were also less durable than coins made with purer copper and were held in poor repute by the people.[50]

In +1068, Su Chhe 蘇轍, brother of the famous Su Shih 蘇軾 (Su Tung-pho 蘇東坡), was serving as Vice-Director in the Ministry of Revenue (*hu-pu fu shih* 戶部副使). A merchant came to the ministry to report a 'secret method' (*mi fa* 秘法) by which one could 'rub' iron with gall vitriol and turn it into copper (*neng i tan fan tien thieh wei thung che* 能以膽礬點鐵為銅者). After his colleagues expressed doubt that the method would work, Su had an experiment run using the merchant's explanation. It failed to produce the transformation.[51] Not many years later, Shen Kua's account in his 'Brush Talks from the Dream Brook' (*Meng Chhi Pi Than* 夢溪筆談) (*MCPT*) of how copper was obtained from vitriol at Hsin-chou 信州, an account borrowed directly from the *Tan Fang Ching Yuan* 膽房鏡源 (The Mirror of Alchemical Elaboratory, A Source-book),[52] talks only of boiling vitriol water and makes no mention of precipitation on iron.[53] Both of these examples suggest strongly that the wet copper process was not yet well known or in wide use in the +1060s to +1080s. This makes reasonable the later tradition that the first implementation of the process by the government, making use of 32 springs of vitriol water, occurred in +1086.[54]

Even in the last decade of the +11th century and into the first decade of the +12th, however, the wet copper process may well have continued to retain something of an experimental character. By the mid- to late +1090s, under the direction of an official by the name of Yu Ching 游經 who had developed a special interest in this process, copper precipitation works had been established at Hsin-chou, Jao-chou, Shao-chou 韶州 and Than-chou 潭州 (cf. Map 15) and production was increasing rapidly. When Yu Ching then resigned to go into mourning, not only did the expansion of the process to new sites come to a halt[55] but production at existing installations rapidly slumped to half or less of its previous highs. Only when Yu Ching returned to office did production not only recover but also resume its earlier rapid growth.[56]

the norm in the +1140s, the evidence from the metallic content of Southern Sung coins suggests that the relatively high percentages of iron (compared to the coins of the Northern Sung) resulted from the extensive reliance on copper obtained by means of this process; Cf. *Sung Shih*, ch. 180, p. 4394 and Chao Khuang-hua *et al.* (*1986a*), pp. 327–9. Be that as it may, the Southern Sung coins, with their maximum iron content in the 4% range, contained far less than the well over 10% or even 20%+ iron content occasionally found in ancient currencies elsewhere; Craddock & Meeks (1987).

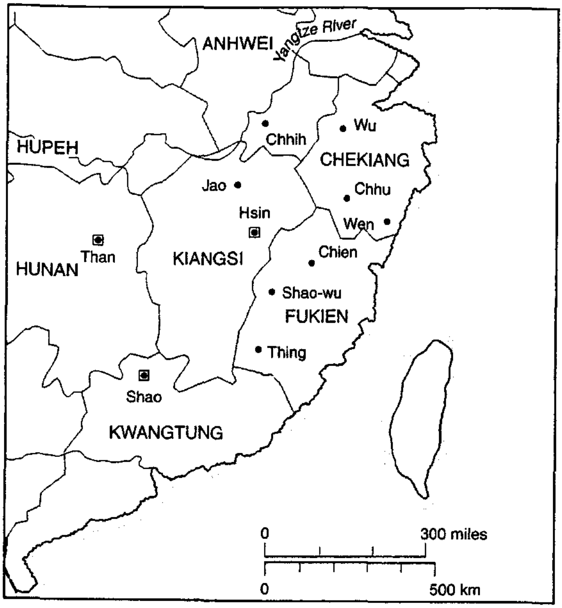
50 *HCP*, ch. 40, pp. 923–4; Yen Yü (*1957*), p. 70; Chang Hung-chao (*1927*), p. 317; *Kuei Erh Chi*, *hsia*, cited in Yen Yü (*1957*), p. 71. The above hardly represents the last word on this subject. An internet discussion among a number of members of the Arch-metals group, carried on in August/September 1995, made it clear that there remained much work to be done on of the effects of iron, especially > 2%, in a copper–iron alloy.

51 *Lung Chhuan Lueh Chih*, ch. 5, p. 3a; Lung Tshun-ni (*1986*), p. 152; Lung Tshun Ni (1986), p. 117. Lung speculates that the experiment 'failed' because it was not given enough time ('the reaction . . . between a copper sulphate mineral and an article in physical contact is very slow and not easily noticed') and that the use of an aqueous solution instead of the mineral itself, where the reaction would have taken place much faster, 'must have been the merchant's secret not mentioned to the officials'.

52 Kuo Cheng-yi (*1981*), p. 67. 53 *MCPT*, ch. 25, p. 792.

54 *Wei Thai-phu Wen Chi*, ch. 10, p. 12a. 55 *SHY:SH*, ch. 34, p. 25a.

56 The story is well told, with references to all the primary sources, in Nakajima (*1940*), pp. 398–400.



Map 15. Main vitriol copper production centres in the Sung (+11th and +12th centuries). ▣ 3 largest producers. • Other producers or possible producers. (Present-day province names and boundaries.) Based on *SHY:SH*, ch. 33, pp. 18b–19b (1166); ch. 34, p. 21b (1165) and p. 25a (1101); *WHTK*, ch. 18, p. 181a; Lung Tshu-ni (1986), p. 121.

This episode reveals one of the most important aspects in the story of the implementation of industrial-scale production of copper by precipitation in the Sung. Without the efforts of officials who came increasingly to look upon the production of copper from vitriol waters as a way to supplement the declining amounts of copper available from regular deposits, it is extremely unlikely that the process would have been developed and become as prominent as it did in the Sung.[57] Like all Chinese governments since the political unification of China by the Chhin in −221, the Sung government relied mainly on copper alloys to mint the coins that were the major component of the currency system. The Sung, however, witnessed an unprecedented monetisation of government finances, especially in the +11th century.[58] In part because of the new fiscal demands, the government had to vastly expand its minting activities. It has been estimated that from +960 to +1125 the Northern Sung government minted some 200,000,000 strings of cash which, at the normal rate of 770 cash coins to the string, would have totaled 154 billion coins.[59] If this estimate is correct, it suggests that the government needed a minimum of some

[57] *SHY:SH*, ch. 34, p. 25a. As early as +1098, the government had already decreed a monopoly on all copper produced from vitriol waters; *SHY:SH*, ch. 34, p. 25b.

[58] Chhen (1965) esp. pp. 618–19.

[59] Gernet (1982) p. 324; Shimonaka (*1959–1962*), Vol. 5, pp. 315b–316a. For the Sung government's copper needs and policies, see Golas (1989), esp. p. 414.

380,000 tonnes of copper to meet its coinage needs during the Northern Sung.[60] This is not an unreasonable amount when we recall that copper production in the Northern Sung reached a peak of 15,000 tonnes yearly in the 1070s.[61] Of course, not all of that copper needed to be newly mined; much of it was metal obtained by melting down old coins.[62] Nevertheless, there was a large and steady demand for copper on the part of the government (and, to a much lesser extent, among the populace).

Successful efforts on the part of the government to stimulate copper production culminated in +1078 in the mining and smelting of more than three times as much copper as in +997, an amount that one scholar has estimated to be ten times the copper produced in China in 1930![63] In +1073 and again in +1080, the government minted some 6,000,000 strings of cash, the highest single year totals in the entire imperial period, not excluding the Chhing.[64]

China's extensive but not especially large copper deposits could hardly bear up indefinitely to that kind of exploitation.[65] Already by the middle third of the +11th century, exhaustion of existing mines had led to shortages of copper at the government mints.[66] The shortages became even more serious by the end of the reform period. The most dramatic evidence of declining production was the cessation of mining operations in +1085 at Tshen-shui 岑水 mine at Shao-chou 韶州 in Kwangtung,[67] the mine that, nine years earlier, accounted for 87 per cent of all China's recorded copper production! Overall copper production declined by almost one-third between +1078 and +1106.[68] It was these circumstances that made the efforts of Yu Ching so welcome.

Over at least the next several decades, vitriol copper production increased to the point where as much as one-quarter or more of China's now shrunken overall copper production may have derived from this source.[69] Moreover, the government

[60] Allowing a weight of 3.73 grams for each coin (Hartwell (1967), p. 280, fn. 5), 596.82 grams to a *chin*, and 1520 *chin* to a short ton. I have also assumed a very conservative 60% average copper content in the coins (Chao Khuang-hua *et al.* (*1986*), pp. 230–7). For the year +1080 alone, the mints would have required just under 10,000 tonnes of copper; Golas (1989), p. 414.

[61] Section (*e*)(1)(i)(ε) above; Vogel & Theisen-Vogel (1991), p. 57.

[62] Cf. for example *Sung Shih*, ch. 180, pp. 4394–5.

[63] Golas (1989), pp. 412–13; Hino (*1935a:1983*), p. 295; Ma Yun-kho (*1932*), p. 54. (The estimate is Ma's.)

[64] Gernet (1982), p. 325; Pheng Hsin-wei (*1954*), p. 281; Huang (1974), pp. 75–6; Vogel (1987), p. 10. We have no total figures for the intervening years of the Yuan and Ming.

[65] Yunnan, with its rich deposits that would provide most of the government's copper in the latter Ming and the Chhing dynasties, was not part of the territory controlled by the Sung state.

[66] *HCP*, ch. 120, p. 2837 [+1037]; Kuo Cheng-i (*1983*), p. 59. [67] *SHY:CK*, ch. 42, p. 119b; Nakajima (*1940*), p. 396.

[68] Hino(*1935a:1983*), p. 295. This sharp decline in production is reminiscent of a similar boom-and-bust cycle in Europe several centuries later. In the first half of the +16th century, when European copper mining and smelting flourished, average yearly production was not much under 5,000 tonnes. In the second half of the century and into the first years of the +17th century, the total sank to 2,000 or fewer tonnes per year; Vogel & Theisen-Vogel (1991), pp. 6–7.

[69] Chhi Hsia (*1987–1988*), Vol. 2, pp. 560–1; Hua Shan (*1982*), pp. 119–21; Hsia Hsiang-jung *et al.* (*1980*), pp. 96–7. For production figures, see *SHY:SH*, ch. 33, p. 18b; *CYTC*, *chia*, ch. 16, p. 8b; Lung Tshun Ni (1986), p. 121. By the middle of the +12th century, government documents commonly distinguished between copper produced by smelting (usually *huang thung* 黃銅, sometimes *shih thung* 石銅) and copper produced by precipitation on iron (*tan thung* 膽銅); *CYTC*, ch. 16, pp. 8b–9b (502–4). The wet copper process even brought new life to mines that had been closed either because the deposits were worked out or had ceased to be economical. For at least a time, the famous mines at Chhien-shan hsien 鉛山縣 of Hsin-chou 信州 (present-day Shang-jao hsien 上饒縣 in Kiangsi) and Te-hsing hsien 德興縣 of Jao-chou 饒州 (present day Po-yang hsien 波陽縣 in Kiangsi) produced copper only by means of precipitation of vitriol waters; Kuo Cheng-i (*1983*), p. 59.

also found that the cost of copper production by the wet copper method was considerably less than that for copper produced by normal mining and smelting; in +1102, for example, it was estimated that the mints could save more than 600 cash on each string minted by using copper produced from vitriol waters.[70] The process could also produce useful side products such as 'gall (bitter) alum' (*tan fan* 膽礬), i.e. copper sulphate.[71] As suggested above, however, the corollary of these savings seems to have been a lower quality copper.

The spread of the wet copper process in the +12th century testifies not only to a need for new sources of copper but also to the ready availability of inexpensive iron in the large amounts necessary to make the process economically feasible. At a minimum, it appears that 2.25 *chin* of iron were consumed for every *chin* of copper produced.[72] On the other hand, the ratio of iron to copper could, according to Chang Tuan-i 寂端義's early +13th century *Kuei Erh Chi* 貴耳集 (Collected Notes of an Invaluable Ear), be as high as 5:1.[73] Actual site figures from around +1165 suggest that it typically took at that time from 3.25 to 4.25 *chin* of iron to produce one *chin* of copper, figures very similar to the experience at copper cementation works in Kiangsi in the early 1980s.[74]

At peak production, just under 2,000,000 *chin* or about 1,300 tonnes of copper were being produced yearly by the cementation process.[75] Using a 4:1 ratio, that would have required something over 5,000 tonnes of iron, not an especially large demand for an industry than could produce as much as 100,000 tonnes of iron and more every year.[76] Thus, in the texts that have come down to us, there is no hint that availability of iron was at all a concern for the officials during the Northern Sung or in the early Southern Sung. Indeed, instead of using scrap iron as in modern implementations, the government seems to have found it easier and perhaps even more economical to use thin plates of newly cast iron to maximise the efficiency of precipitation. Whole ironworks came to be specifically charged with supplying the iron needed.[77] In +1116, the entire 2,890,000 *chin* of iron bought up by the officials in Kuang-nan-tung 廣南東 circuit (roughly present-day Kwangtung province) was used exclusively for the copper precipitation process.[78] In the course of the +12th century, however, the general decline of the mining industry (or at least

[70] *SHY:SH*, ch. 34, p. 25b. See also the calculations in Chhi Hsia (*1987–1988*), Vol. 2, p. 562. Even the production of copper from vitriol-bearing earth, though 60% more costly than starting with vitriol water, was still far more economical than normal mining and smelting; *SHY:SH*, ch. 34, p. 25b.

[71] *MCPT*, ch. 25, p. 794.

[72] *CYYL*, ch. 59, p. 1980 [+1132]; *Sung Shih*, ch. 180, p. 4394 [+1143]. Modern chemistry confirms this as a reasonable ratio. According to Lung Tshun-ni: 'Theoretically, the amount of iron required to precipitate 1 kg of copper is 0.88 kg, but in practice iron consumption is much higher, between 1.5 and 4.0 kg per kilogramme of copper. The excessive consumption of iron is induced by side reactions; for instance free acid and ferric ions can react with iron too. So an iron consumption ratio of 2.25 . . . is reasonable and falls in the normal range.' Lung Tshun Ni (1986), pp. 119–20.

[73] *Kuei Erh Chi*, ch. *hsia*; cited in Hua Shan (*1982*), p. 135, n. 22.

[74] *SHY:SH*, ch. 33, pp. 19a–23a; Kuo Cheng-i (*1983*), p. 61.

[75] Lung Tshun Ni (1986), p. 121. [76] Cf. above, Section (*e*)(3).

[77] *SHY:SH*, ch. 34, p. 26a [+1178]; Sung *Shih*, ch. 180, p. 4394; *SHY:SH*, ch. 33, pp. 19a–23a; Lung Tshun-ni (*1986*), p. 11; Nakajima (*1940*), p. 408.

[78] *Sung Shih*, ch. 185, p. 4528; Nakajima (*1940*), p. 407.

the government's control over it) brought dramatically changed conditions so that, by the end of the century, shortages of cast iron imposed severe limits on the use of the precipitation process.[79]

(3) Post-Sung Decline

Lack of iron might well be part of the answer to the intriguing question of why there are so few references to use of the copper precipitation process after the Sung.[80] In the *Yuan Shih* 元史 (Official History of the Yuan Dynasty), for example, there is no mention of it at all.[81] Actually, we do know from other sources that there were at least two attempts (the second in +1352) to reimplement the process in the +14 century. In both, the Yuan court was responding to presentations by descendants of Chang Chhien 張潛, the first and perhaps only author of a manual describing the process. Neither case led to successful production, for reasons that are not clear from the sources available to us.[82] In the +17th century, Sung Ying-hsing in the *TKKW*, which gives a rather good description of much of the technology of his day, seems not to have understood the process: 'A heated iron article quenched in an aqueous solution of gall vitriol *becomes the colour of copper*.'[83] We also have explicit evidence from the same period that at Kuang-hsin fu 廣信付 (the former Hsin-chou 信州 of the Sung), the officials had taken over the areas in Chhien-shan hsien 鉛山縣 suitable for copper precipitation and forbade the people to use the process.[84] From the late Ming through the Chhing (+16th to 19th centuries), a fair amount of evidence suggests that, while awareness of the earlier use of the process was maintained, especially in a number of geographical works, it pretty much died out in practice.[85]

In addition to perhaps a lesser availability of iron and therefore its higher cost, one can suggest other reasons for the apparent demise of the copper precipitation process after the Sung. Perhaps the best sources of copper-bearing mine waters had, in their turn, been exhausted by the extensive production of the Southern Sung. It has also been speculated that the Yuan government may have been unable to manage effectively the extensive precipitation works and the accompanying refining furnaces.[86]

[79] Hsia Hsiang-jung *et al.* (*1980*), p. 100. Thus, in the early +13th century 'Ta Yeh Fu' 大冶賦, Hung Tzu-khuei suggests that the use of scrap iron in the process had become the norm; *Phing Chai Wen Chi*, ch. 2, p. 5a.

[80] Vol. 5, pt. 4, p. 204; Lung Tshun Ni (1986), pp. 120 and 124; Chang Hung-chao (*1954*), p. 53.

[81] In the chapters on fiscal administration, there is one surprisingly incomplete listing of five places producing copper, none of which is a location known for use of copper precipitation in the Sung; *Yuan Shih*, ch. 94, p. 25412a; Schurmann (1956), p. 153; Nakajima (*1940*), p. 415.

[82] Nakajima (*1940*), p. 415.

[83] *TKKW*, ch. 11, p. 204, translated in Sun & Sun (1966), p. 209, emphasis added. Hsia Hsiang-jung, Li Chhung-chün and Wang Keng-yuan point out that Sung's silence on any use of the process in an industrial context is significant. We know from the *HWHTK* (Continuation of the *Comprehensive Study of (the History of) Civilisation*) and the *Ming Shih* (History of the Ming Dynasty) that the process was revived for an unknown period of time in the early +15th century at Te-hsing 德興 and Chhien-shan 鉛山 in Kiangsi. Since Sung was a Kiangsi native, he would presumably have known of it if this kind of copper production was still being carried on at those places; Hsia Hsiang-jung *et al.* (*1980*), pp. 150–1; Chang Hung-chao (*1927*), p. 317. (In +1428, the production of copper by precipitation in these two counties totaled 250 tonnes; Zhu Shoukang (1986), p. 9.)

[84] *Ta Ming I-thung Ming-Sheng Chih*, ch. 6, cited in Nakajima (*1940*), p. 417. [85] Nakajima (*1940*), pp. 416–20.

[86] Hsia Hsiang-jung *et al.* (*1980*), p. 127.

Perhaps over time improvements in copper smelting, especially the ability to process sulphide ores, narrowed the cost advantages of the precipitation method. In the Yuan and early Ming, currency changes, foremost of which was the use of paper money, greatly reduced government demand for copper. Even later, after the government had restored bronze coinage as a key part of its currency system, the use of coins was greatly supplemented by the vast increase in the availability and use of silver in economic transactions. The change began with the domestic silver mining boom in the early +15th century and was spurred on by the massive inflows of foreign silver in the +16th and early +17th centuries, and again in the +18th century.[87] The increasing reliance on silver did not mean that the government was now immune to periodic copper shortages, for example in the +17th century.[88] But in the changed circumstances, it may well have been that these were less severe than the shortages of Sung times. Certainly, the consistency of copper output over much of the Chhing was in marked constrast to the striking fluctuations that marked the Sung.[89]

This raises the question of whether and to what extent we are dealing here with a real abandonment of the copper precipitation process or merely with the appearance of decline emanating from the silence of texts almost all of which emerge to a greater or lesser extent from the official milieu. It is perhaps of some significance that later centuries witnessed at least one major development related to this process. By the +15th century, the Chinese had discovered that metallic lead or tin could substitute for iron in the wet copper process.[90] It could well be, as Yen Yü suggests, that the government lost interest in the process – hence the general silence of the texts – but that it continued to be of some importance at small private mines.[91]

Finally, it comes as something of a surprise to discover that this process had a rebirth in China in the post World War II period. It was used from 1944 to 1982 by the Taiwan Metal Mining Corporation at the Chin-kua-shih 金瓜石 mine on the coast of northern Taiwan (Fig. 122). With methods much the same as those of the Sung, Chin-kua-shih production averaged around 600 tonnes per year in the 1970s and, until the declining copper content in the waters dropped below an economically workable level, it was the least expensive method available for producing copper.[92] The process was also promoted by the government of the People's Republic in certain areas during the Great Leap Forward of the late 1950s and, as we have seen, was still in use in some places into the early 1980s.[93]

87 Atwell (1982), esp. pp. 76–7; Atwell (1986), Eastman (1988), p. 129.

88 Vogel & Theisen-Vogel (1991), pp. 19–20. 89 *Ibid.*, p. 14.

90 *Shih Thien Tsa Chi*, cited in Lung Tshun-ni (*1986*), pp. 16–17 and translated in Lung Tshun Ni (1986), p. 124; Hsia Hsiang-jung *et al.* (*1980*), pp. 269–70. A variation on the normal wet copper process employed straw mats at the bottom of the sluices through which the vitriol waters flowed. Here too, small pieces of iron would be placed in the sluices but the process would be allowed to continue until the iron had completely disintegrated. The copper powder could then be collected from the straw mats. Unfortunately, we have no idea when this process was first used; *TSFYCY*, ch. 85; Chang Hung-chao (*1954*), p. 33; Lung Tshun-ni (*1986*), p. 149.

91 Yen Yü (*1957*), p. 71. Nakajima (*1940*, p. 421) does not agree.

92 Lung Tshun Ni (1986), p. 124; (*1986*), p. 153. Again through the kindness of Mr Lung Tshun-ni, who had formerly been in charge of the installation, I was able to visit in 1988 what little still remained of those works. We were even able to find a few pieces of scrap iron with precipitated copper powder on them.

93 Chang Tzu-kao (*1964*), p. 107; Hsia Hsiang-jung *et al.* (*1980*), p. 271; Kuo Cheng-i (*1983*), p. 61; Lung Tshun-ni (*1986*), p. 153.

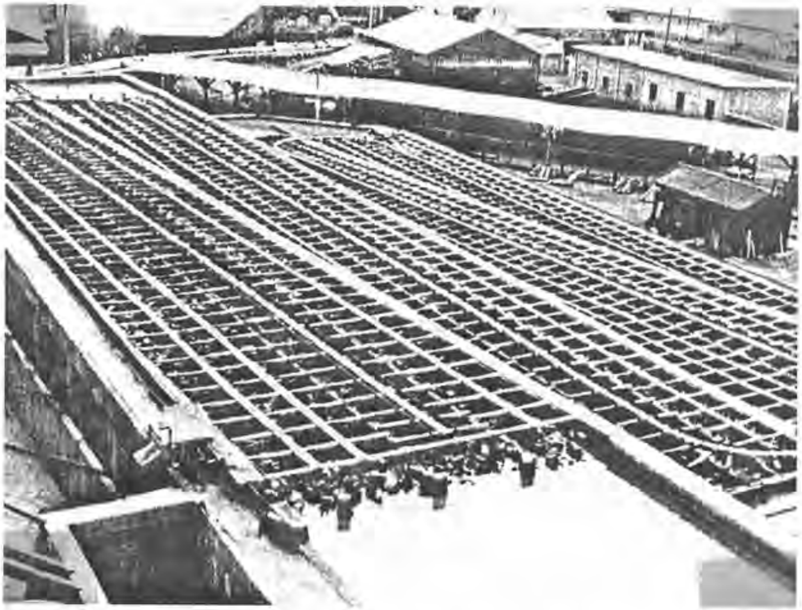


Fig. 122. Installation at Chin-kua-shih 金瓜石, Taiwan for precipitation of copper from mine waters. Photograph by Lung Tshun-ni. Anon. (1970), pp. 11–12; Lung Tshun-ni (*1986*), p. 18.

The earliest commercial use of the wet copper process in northern Europe seems to have occurred in the late +15th century,[94] that is, some five centuries after commercial development of the process in the Sung.[95] By the +16th century, it was an 'established industry' in Hungary[96] and Hungary seems to have remained Europe's major centre of production into the +18th century. Already in the early +17th century, however, the process was widely known throughout Europe and was at least experimented with in Sweden, Norway, the German-speaking areas of central Europe, and the Venetian Republic.[97] In the 19th century it was also being used commercially in Spain (Rio Tinto), Ireland, and England.[98] Even in modern times, knowledge of the process did not necessarily imply economic viability. At Butte, Montana in the USA, it took 13 years, from 1888 to 1901, to make the process commercially successful. In 1910, 2279 tonnes of copper were produced there by precipitation on scrap iron.[99]

Where the process could be made to work, however, it represented a major advance in the technology of mining. Not only, as we have noted above, did it represent the world's first industrial use of a hydrometallurgical process. It also opened the

[94] Vol. 5, pt. 4, p. 203, fn. (e).

[95] This process was also discovered by the Moors in Spain. Hassan & Hill (1986), p. 249; Read (1937); Bromehead (1956), p. 11.

[96] Multhauf (1958), p. 53. For Agricola's description in *De Natura Fossilium* of the process used in Smolensk, Hungary, see Bandy & Bandy (1955), p. 188.

[97] Searle (1938), chapter III; Kunnert (1974), p. 195.

[98] Checkland (1967), pp. 58ff.; Lung Tshun Ni (1986), p. 125. [99] *Ibid.*

way to the economical use of low grade ores, something that became increasingly necessary after the industrial revolution had brought about the exhaustion of many of the richer copper ore deposits. The process, first experimented with in the Sung, of excavating low quality sulphide ores and then converting the insoluble sulphide into soluble copper sulphate by oxidation during weathering could later be speeded up by setting fire to the ore which largely burned of itself through the combustion of the pyrite, though with dreadful ecological damage caused by the sulphurous acid that passed into the atmosphere, thus destroying the surrounding vegetation.[100] It was this process that brought back to vigorous exploitation in the mid-19th century the world's largest massive copper sulphide deposits, the famous 'mines of Tharsis' in southern Spain.[101]

100 This process was used at Agordo in the Venetian Republic at least by the early +18th century; Searle (1938), p. 61.

101 Checkland (1967), pp. 13, 59. The fact that the ore, once ignited, was self-combusting meant that vast quantities of ore could be treated this way without the great fuel costs that would have been involved in smelting; *Ibid.*, p. 60.

(*k*) LABOUR, CAPITAL AND MINING TECHNOLOGY

(1) Mining Labour in Early Chinese Mining

By the second half of the –2nd millennium, some Chinese mining operations had advanced in scale and technique well beyond the surface diggings or shallow shafts that characterised its earliest stages. Even without other evidence, we would be led to such a conclusion by the vast amount of copper that was obviously necessary to support the flourishing bronze industry of the Shang ((*e*)(1)(i)(β)). We also have, however, more direct evidence in the remains of early copper mines such as those of Jui-chhang 瑞昌 and Thung-lü shan 銅綠山 ((*e*)(1)(i)(δ)).

In an effort to flesh out the character of the mining industry in Shang times, Ursula Franklin has postulated a 'well-organised large-scale' mining industry where the difficulties and dangers of the work would have made it necessary to rely on 'a large pool of forced labour'. The major weakness in this interpretation is that there is not a shred of evidence, either archaeological or textual, to support it.[1] As William Meacham has pointed out, we know nothing of what incentives might have been offered to encourage people to work in mining or smelting. The history of mining even in modern times provides abundant examples of the willingness of workers, prompted by material or other incentives, to take up mining even where it was much more unpleasant and even dangerous than other occupations available to them.[2] Moreover, we need to know much more about actual mining in China at this time, instead of just retreating into unfounded generalisations along the lines of 'some characteristics of mining operations apply to the process per se – whenever and wherever it took place.'[3] Finally, what evidence does survive suggests that the Shang 'made no special effort to incorporate' into its sphere of direct, regular control even the area on the Shensi-Honan border where copper and tin deposits were especially abundant.[4]

(2) The Mining Labour Force

> Thousands [millions!] of men have worked in mines without ever having been miners.
>
> *Tom Morrison*[5]

In general, four major groups made up the mining labour force in traditional China.

[1] Franklin (1983), p. 287; Rostovtzeff (1941), p. 287. As her citation of *The Social and Economic History of the Hellenistic World* suggests, Franklin has been much influenced by Rostovtzeff's characterisation of Hellenistic mining. It should not need to be said that interpretations supported only by evidence from societies at a very different stage of development in a totally different culture are highly tenuous at best. They can even be counter-productive if they are allowed to skew the assessment of what small amount of evidence is available to us. As Barnard notes: '. . . there is nothing [in the written oracular records or in the archaeological evidence] to suggest . . . enforced employment in mining activities or that mining was almost solely conducted on the basis of forced labour.' Barnard (1989), p. 144; see also pp. 195ff.

[2] Meacham (1978), p. 153.

[3] Franklin (1983), p. 287.

[4] Keightley (1983a), p. 551. The topic of forced labour in the Shang has been ably explored by David Keightley (1969). The silence of the sources is reflected in the fact that he has nothing substantial to say specifically about mining labour in the Shang.

[5] Morrison (1992), p. 5.

(1) A very large segment in terms of number of workers though much less important in terms of total production consisted of those peasants who owned or leased farmland but who did some mining in the off season to supplement their small incomes.[6] They thought of themselves mainly as farmers, not as miners.[7] Such side-employment mining was typically carried on by individuals, by families, or by other very small groups of workers. For example, groups of seven or eight men seem to have been very common in gold placering, one of the most common of mining side-employments.[8] Only in rare circumstances did one see exceptions such as the large numbers of Fukien peasants in the Ming, hundreds and perhaps thousands of whom migrated after the harvest to Shao-chou 韶州 and Hui-chou 惠州 in Kwangtung to work as iron miners, but returned to their homes for the spring planting.[9]

Most of the peasants who practised mining and mining-related activities in the off season were undoubtedly grateful for any kind of opportunity to supplement their meagre farming earnings. Side-employment also provided something of a cushion against crop failures. In some cases, as with those Shantung peasants who reworked already twice-treated gold concentrates, the return for their labour was so low that one wonders if the primary benefit was not simply something to do during what otherwise would have been long hours of idleness during the winter.[10]

(2) Another group engaged in mining, similar in many ways to the above, were landless or very land-poor peasants whose survival strategy usually consisted of hiring out as agricultural labourers but who might also turn to mining or other industries such as spinning, weaving and pottery making, usually in or very close to their home area.[11] Indeed, the same men might work part of the year as agricultural labourers, part of the year as miners; Teng Tho thinks that this accounts for the fact that the Men-thou-kou 門頭溝 coal mines were worked only from the 8th month of

[6] In Europe, sideline mining by peasants was typically confined to iron and coal mining; Nef (1952), p. 449. This may generally have been the case in China, but there were important exceptions, such as gold panning. At the quicksilver mines in eastern Kweichow early in this century, the relatively strong and healthy farmers (who benefited from working outdoors in a healthy climate) avoided, even in the off-season, unhealthy work as miners *per se*, even though they did some picking of ore 'from mine dumps both inside and outside the mines'; Brelich (1904), p. 486.

[7] Carlson (1971), p. 44.

[8] di Villa (1919), p. 85; von Richthofen (1874), p. 4; Lu Pen-shan & Wang Ken-yuan (*1987a*), p. 271.

[9] Eberstein (1974), pp. 145–6. Hartwell writes of +11th century iron mining and smelting in eastern Shantung as carried on 'during the idle season by peasants whose primary occupation was farming' and suggests that they 'were apparently organised into groups that resembled the so-called *arbeitsgenossenschaften* (*sic*), or laborers' associations, described by Gustav Schmoller' (Hartwell (1966), pp. 41–2). Unfortunately, Hartwell presents, and I know of, no evidence to support such speculation in this particular case. Indeed, insofar as there were in China miners' groups such as those described by Schmoller, they would most likely be found in our fourth group, though even here their organisation would take on manifestly Chinese forms.

[10] Read (1907), p. 1297. But compare Scott (1976, pp. 13–14) drawing on Chayanov's concept of the 'self-exploitation' often found among poverty-stricken peasants.

[11] For a full discussion of this group in the Ming, see Eberstein (1974), pp. 147ff. and Pai Shou-i (*1960*), p. 987. In the Chhing, the meagre three strings of cash a month earned by a miner at the Men-thou-kou coal mines west of Peking was still more than what could be earned by an agricultural labourer in the same area; Cartier (1967), p. 84.

the year to the 5th month of the succeeding year.[12] Under certain conditions, such part-time workers might evolve into the full-time miners discussed below.

(3) A third group consisted of those who were physically compelled to work as miners. The government, for example, at different times and on varying scales compelled soldiers and convicted criminals to work in mines managed directly by officials.[13] Under some dynasties such as the Ming, mining could be a labour service owed by a part of the population at large to the government[14]. Then there were also those who ran afoul of private mine operators or headmen (through gambling debts, unpaid loans, hiring under false pretenses,[15] or even straight impressment). Some of the most horrendous stories of mining conditions refer especially to these latter unfortunates, sometimes referred to as 'dead labour' (*ssu-kung* 死工) as opposed to 'living' or free labour.[16] This group seems to have made up a small part of the total mining force, at least in recent centuries.[17]

(4) Finally, there were those who chose mining as a full-time or nearly full-time occupation (though they might spend only a part of their lives as miners). Lack of any alternative ways to make a living or the burden of debts were probably the major, though not the only, stimuli that led boys and men to become miners.[18] Sometimes mining offered better pay than other employment open to them, for example, as agricultural workers or weavers or carpenters.[19] Tim Wright notes that their income might even approach the income of a middle peasant.[20] Other reasons for taking up mining might be avoidance of military service; a shorter or more flexible working schedule;[21] or escape from family problems.[22]

To understand the character especially of the full-time miners, we must be careful not to attribute to them inappropriate similarities to miners in other cultures. We have spoken, for example, of their choosing mining as a full-time occupation, avoiding the word 'profession'. As we shall see below, their position was far different from that of the mining élite in central Europe, especially southern and eastern Germany, in the late medieval and early modern periods.[23] Nor do we typically find prospectors roaming over hundreds and even thousands of miles in search of the big strike, as was true for many miners in the 19th century American west. Because of the massive labour reserves of the Chinese countryside, probably the overwhelming

[12] Cartier (1967), p. 84.

[13] Soldiers were used as miners especially in lightly settled or strategically important areas and where there were arsenals; Vogel & Theisen-Vogel (1991), p. 32.

[14] Golas (1989), p. 414; Eberstein (1974), pp. 139–42, 162–7, 169; Pai Shou-i (*1960*), p. 971. The Chhing (+1644 to 1911) rulers, appalled by the excesses of the previous Ming dynasty's forced labour policies, virtually abandoned any use of soldiers, prisoners or peasants on labour service in mining; Vogel & Theisen-Vogel (1991), p. 33.

[15] Lü Tai-ming (*1986*), p. 174.

[16] Cf. Ebrey (1981), pp. 233–4; *SHY:HF*, ch. 2, pp. 147a–b; Moller (1909–1910), p. 473; Chesneaux (1968), pp. 60–1; Sun (1967), p. 56; Wright (1984), p. 167. Conditions in official-run mines could be equally bad; Eberstein (1974), pp. 141–2.

[17] Wright (1984), p. 166.

[18] A sample of 100 miners at Ko-chiu in the 1930s had 78 giving these two as the reasons why they took up mining; Su Ju-chiang (*1942*), p. 62.

[19] Cartier (1967), p. 84. [20] Wright (1984), p. 78. [21] Brelich (1904), pp. 485, 488.

[22] Su Ju-chiang (*1942*), p. 62. [23] Nef (1952), pp. 473ff.; Eberstein (1974), pp. 138, 200.

majority of these professional miners never found themselves more than 200–300 km at most from their home village or town.[24] The government, well aware that the small minority of highly mobile miners could cause trouble out of all proportion to their numbers, sometimes consciously tried to limit the miners' mobility, for example by punishing those who left their native area in order to work as miners elsewhere.[25] To be sure, its power to implement effectively such policies was very limited.[26] But insofar as they could be implemented, such policies may have had at least a marginal negative impact on the spread of mining expertise and the development of mining in general. The very effort to do so stands in stark contrast to the policies of European governments in the late medieval and early modern period which recognised mobility as an intrinsic element of the mining industry and legalised the right of miners to travel where their opportunities took them.[27]

Mobility *within* large mining complexes like the tin mines at Ko-chiu 箇舊 might be considerable, however. In the 1930s, far fewer than half the Ko-chiu miners had worked at the same mine for more than three years.[28] They might even return home at harvest time either because their families needed their labour or because, at that time of the year, agricultural work paid better than mining.[29] Some of the miners probably also found agricultural work a welcome break from work in the mines. In any case, many of them would certainly try to return home on important occasions, especially for the celebration of the new year.

This retention of ties with one's native place even through long periods of living and working elsewhere[30] gave a character to Chinese mining communities that differentiated them from many mining communities in other cultures. In general, the isolation of the mines, the working conditions that often require miners to work in close proximity to one another, the very danger of the work often produce in mining communities a highly developed sense of camaraderie. Such a heightened sense of community was less to be seen in Chinese mining camps or towns, not only among the miners but even among the resident families. A major reason was the persistence of native-place ties. As Shih Kuo-heng wrote about Ko-chiu in the immediate post World War II period:

[24] Eberstein (1974), pp. 150–1. The continuing association of full-time miners with the agricultural communities from which they came, together with the prevalence of mining as a sideline activity of peasants, was undoubtedly a major reason why even full-time miners in China were typically seen and treated by the government in the same way as peasants rather than as a truly distinctive social group; Vogel & Theisen-Vogel (1991), pp. 53, 56.

[25] *Ta Chhing Hui Tien*, ch. 247, citied in Anon. (*1983*), Vol. 1, p. 5; Collins (1922), p. 29; Eberstein (1974), p. 155; Vogel & Theisen-Vogel (1991), pp. 32–3.

[26] As was the case at least in Chhing times with most of the social policies of the government, very definitely including those that attempted to limit geographical mobility; Naquin & Rawski (1987), pp. 16–17; 20–1. As an example of the considerable mobility that could exist in the mining industry, we need only look at Yunnan where, in the boom times from +1700 to 1850, almost all of the hundreds of thousands of miners were immigrants from other parts of south and southwest China (mainly Hu-kuang, Kiangsi and Szechwan) who flocked to the mines looking for high wages or quick profits; Lee (1987), p. 236; Satoi (*1972*), pp. 27–8. This is another case where it is impossible to determine how many of these 'miners' were actually full-time miners and how many were peasants or craftsmen seizing upon a good opportunity; Chang Yü-jung (*1963*), p. 39. Of course, many of the latter could well be, knowingly or unknowingly, in transition to becoming full-time miners.

[27] Eberstein (1974), p. 152. [28] Su Ju-chiang (*1942*), pp. 67–8. [29] Chesneaux (1968), p. 51.

[30] A topic that has been extensively explored in Skinner (1976) and Skinner (1977), pp. 538–46.

Fig. 123. Low and narrow gold-mining shafts at Thao-hua 桃花, Kwangsi. Original photo, 1994.

Although many of the resident families came to the city several generations ago, they still retain strong ties with family headquarters in their native villages or towns. On great occasions they go home to visit their parents and worship their ancestors. If they prosper at tin-mining in Ko-chiu, they remit money to their family homes for the purchase of farm land. In the small city there are more than a dozen clubs organized on the basis of provincial or county residence. . . .[31]

One of the great horrors of large-scale mining in traditional China was the frequent use of boys as miners or, more often, as ore haulers and sorters.[32] They might be as young as 8–10 years but typically were 12 years and up.[33] This is often explained as an effort to exploit the cheapest labour available, and there can be little doubt that this was one key motivation. But the very methods of Chinese mining also placed a premium on the widespread use of children in the mines. Because of the narrowness of the shafts and galleries, many of which were more like burrows that the miners had to navigate on their knees or even on their stomachs, small children had an advantage in moving around underground (Fig. 123). There were also many dwarfs in the workforce, most of whom probably started mining at an early age and were prevented by the abominable working conditions in the mines as well

[31] Shih Kuo-heng (1947), p. 54. In Ko-chiu, in 1939, there were 3,300 resident households with 21,914 members and 84,808 mine workers recruited from the surrounding rural areas and without families in Ko-chiu.
[32] Lü Tai-ming (*1986*), p. 218. [33] Pichon (1893), p. 137; Draper (1931), p. 184.

as by their general living conditions from ever reaching their full potential weight and stature.[34]

We have thus far spoken only of men and boys, not of women. This is because female labour seems to have been the exception in traditional Chinese mining, or perhaps we should say inside the mines, especially larger mines.[35] Surviving documents offer few clues as to why. We can only speculate that the very nature of the work provides some explanation, as do the conditions in which it was carried out. Attitudes toward the human body and its display may be part of the answer. Certainly, one can hardly imagine the society or the government in China countenancing women working naked from the waist up in hot mines as occurred quite nonchalantly in some Japanese mines. In north China, widespread use of footbinding would have made it still harder for women to work as miners.[36] Only in surface or perhaps relatively shallow workings carried on by peasants as a subsidiary occupation as well as in ore dressing[37] or other surface tasks such as converting wood to charcoal[38] or smelting tasks[39] did women sometimes play a significant rôle.[40]

(i) *Sectoral distribution of mining labour*

We have already drawn (in Section (*b*) above) on the detailed study of the Chinese mining labour force carried out by Boris Torgasheff in the 1920s.[41] Extrapolating from Torgasheff's estimates, we were able to suggest that, in the early years of this century, perhaps one per cent or some four million Chinese were engaged in mining on either a full-time or a part-time basis. Torgasheff also attempted to estimate in some detail the number of miners working in different sectors of the mining industry, and these estimates are reproduced in Table 1 (p. 2). These figures suffer from the same limitation as his estimates of the overall numbers of people engaged in mining, namely, that they refer mainly to full-time miners and do not adjust for the considerable population who engaged in mining on a less than full-time basis. If we look at the sectors that dominated in terms of number of miners (coal, iron, salt, the clays, stones and sands, and, among the metals, tin/tungsten (wolfram) and gold), we see that, with the partial exception of tin, antimony and salt, these were precisely the sectors where peasants could and did practise mining extensively on a part-time basis. Therefore, Table 1 not only reproduces Torgasheff's estimates but also converts them to percentages which probably give a fairly good overall picture of the distribution of Chinese miners in the various mining sectors.

[34] Huang Chu-hsun (*1930*), p.55; Collins (1909–1910), pp. 188–9; Su Ju-chiang (*1942*), p. 64.

[35] Wright (1984), p. 161; Shih Kuo-heng (1947), p. 54, fn. 2. This contrasts with a much greater rôle for women in European and Japanese mining. For example, more than half of all mine employees in Russia during the 1830s were women; Multhauf (1978), p. 113.

[36] Wright (1984), p. 162. [37] Brelich (1904), p. 486.

[38] Moore-Bennet (1915), p. 217. [39] Satoi (*1972*), p. 28.

[40] In large part, this conclusion rests on an argument from silence, and must therefore be treated with caution. Nevertheless, one would expect women, had they been present, to show up explicitly especially in those writings that describe the hardships of miners. That they do not is strong evidence that they did not ordinarily work in mining.

[41] Torgasheff (1930).

(ii) *Miners' status and expertise*

Mining throughout the world has tended to be a low-status occupation. From early times, it was frequently the work of slaves, convicts and prisoners. Even the much remarked upon rise of miners' status in the late medieval period in Europe benefited only an élite of metal miners.[42] No period in China witnessed any similar improvement in the customarily mean status of miners. In part, this was because most mining work was relatively unskilled; hard and exhausting but easy to learn. The especially close linkage between agriculture and mining[43] may also have hindered any view of miners as an élite. Widespread official disdain of mining, the mobility of some miners and their attenuated local ties, the isolation of their work which placed any real understanding of it beyond most of the populace, and the terrible conditions in which they often worked all served to reinforce attitudes toward miners that included strong components of contempt and fear. Such attitudes were also reinforced by the fact that so much of Chinese mining consisted of coal mining. Coal mining, in addition to the minimal skills required,[44] was especially dangerous in earlier times, and still is. One result was that coal miners found it particularly difficult to get women to marry them, since the women did not relish the real possibility of early widowhood.[45] Moreover, if E-tu Zen Sun is correct, whatever small amount of respectability miners possessed often had a curiously provisional, *ad hoc* character, at least in the eyes of the government. When a mine gave out, officials tended to describe those who had been working the mine not as unemployed miners but rather as 'impoverished people without an occupation' *wu yeh phin min* 無業貧民 or some similar term.[46] Such thinking further stressed the miners' marginality in society and lent support to those emperors and officials who would dispense with mining and miners as far as possible. It may also have contributed in at least a small way to a general lack of interest in labour-saving devices for use in mines.

Yet, even in China, we find enough variation in the social relations among the miners themselves and between miners as a group and the rest of the society to warn against overhasty generalisations.[47] As with artisans and merchants, the two supposedly lowest ranking groups in the traditional Confucian scheme of society, there were successful miners who undoubtedly managed to enjoy considerable prestige.[48] Furthermore, the living and working conditions of professional miners put a premium on cooperation.[49] This in turn often gave rise to an *esprit de corps*

[42] See, e.g., Nef (1952), pp. 477–9. [43] Pai Shou-i (*1960*), p. 991.

[44] Cartier (1967), p. 84 (referring to conditions at the Men-thou-kou mines west of Peking.)

[45] Hung Yü & Wan Chiang (*1958–1959*), Feb. 16, 1959, p. 3. [46] Sun (1967), p. 53.

[47] As one 19th century official put it, '[the miners] have their rituals, which are not the rituals of the sages; they have their morality, which is not the morality of the sages.' Chang Yü-jung (*1963*), p. 41.

[48] In the few dilapidated remains of big houses from the glory days of Ko-chiu tin mining (Fig. 124), one can see hints of the lifestyle of those few miners who struck it rich and were able to forsake working themselves, devoting themselves instead to the pleasures of the city; Chhen Lü-fan *et al.* (*1979*), p. 6. See also the career of Wang Ko in the Sung; Eberhard (1957).

[49] Eberstein (1974), pp. 200–1.

Fig. 124. The remains of one of several imposing houses still to be seen in Ko-chiu. They suggest the lifestyle that might be aspired to by those few miners who struck it rich in the tin mines. Original photo, 1990.

marked by a high degree of egalitarianism.[50] At the same time, there are also indications that a hierarchy of status existed among miners no less than in all other areas of Chinese society. Probably at the top of the hierarchy were the mining experts who tended to come from a limited number of areas but who could be found at mines throughout China.[51] Among the best known were miners from Hunan, some of whom we have met above as spearheading the beginning of mining in one area of Kwangsi[52] Much more recently, Cantonese specialists who had a strong sense of superiority *vis-à-vis* other miners were very active in the coal mines of north China.[53]

Usually, however, the sources do not permit us to make a clear distinction between those highly skilled miners with special expertise and the full-time miners

[50] Sun (1967), p. 57. Sun argues that this egalitarianism predominated in the early stages of opening up a mine but then tended to be undercut as the scale of mining and the size of the mining community grew, thus requiring more formal organisation. On the face of it, this is persuasive but the evidence so far available to establish this as a general pattern in Chinese mining is quite limited. Sun's evidence consists for the most part only of rather brief statements (sometimes little more than concise explanations of terms and vocabulary in use) relating to some of the metal mining in Yunnan.

[51] Junghann (1911), pp. 51, 53; Satoi (*1972*), pp. 27, 69. Satoi notes that specialisation was more highly developed among those workers engaged in metallurgy (smelting, refining, etc.) than among miners whose tasks were generally less complicated.

[52] Cf. above, Section (*f*)(2). [53] Junghann (1911), pp. 51, 53.

generally.[54] This is the case with the Shansi miners who were working in Honan gold mines in the Ming,[55] the miners from other parts China who developed metal mining in +18th century Yunnan,[56] and the miners from Hunan who migrated to Anhwei to reopen coal mines after the suppression of the mid-19th century Taiping rebellion.[57]

Given the generally low level of mining understanding and technology, it should not surprise us that the line between experience and real expertise was far from clear. But even officials were able to recognise the need for a certain level of skill, if not quite expertise, for mining to be carried on effectively. Thus, an official attempting to reorganise mining in Yunnan at the end of the 19th century noted in a memorial that 'recruiting miners is different from recruiting militia . . . [for] only those familiar with excavation work underground can be eligible.'[58] In the Ming (+1368 to +1644), the government frequently distinguished those miners on labour service who had some mining expertise from those who did not; the former were used especially in the opening of mines, after which the latter could be assigned to routine mining tasks.[59]

(3) Labour-Contractor Systems

In recent centuries at least, groups of full-time miners working at private – as opposed to government – mines were typically assembled, organised and managed by labour-contractors.[60] Though this practice is often referred to in Western writings simply as the 'contract system', that term is ambiguous, in the case of mining at least, because other kinds of contracts besides those involving mining labourers were also regularly used.[61] Moreover, as could be expected with any system that was used not only throughout China in many different kinds of mining but even among Chinese miners beyond her borders, there were many variations on the practice so that it is appropriate to refer to labour-contractor systems. Nevertheless, all of these systems tended to have certain features in common and it is on the common features that we shall focus our attention, while taking notice of some of the more important variations.

[54] Certainly, even by the early +16th century, specialisation in central European mining probably greatly surpassed anything found in China; see Vogel & Theisen-Vogel (1991), p. 31. In the following centuries, retarded specialisation in Chinese mining went hand-in-hand with general technological stagnation and the persistence of small-scale mining operations as the norm.

[55] Li Ching-hua (*1981*), p. 78.

[56] Lee (1987), p. 236; Eberstein (1974), p. 151.

[57] von Richthofen (1871), p. 17.

[58] Anon. (*1957*), Vol. 7, p. 53; trans. Sun (1967), p. 54, slightly modified.

[59] Eberstein (1974), p. 140.

[60] Many terms were use to refer to labour-contractors, incluing *pa thou* 把頭, *pao kung thou* 包工頭, *pao fan tso* 包飯作 and *kuo thou* 鍋頭. For general discussions of this system, see Imahori (*1961*); Torgasheff (1930a), pp. 533–41; Chesneaux (1968), pp. 57–62. E-tu Zen Sun suggests that contract labour did not play an important rôle in mining until 'toward the last years of the Chhing'; Sun (1967), p. 61. It is not entirely clear what she means here by 'contract labour' but it is certain that the labour-contract systems go back many centuries at least. Ku Yen-wu in an unprinted work that has survived in manuscript provided a good description of how labour-contract systems functioned in +17th century Yunnan mines; *Chao Yü Chih*, *tshe* 39, 'Yun-nan phien'; the passage is cited in Chhen Lü-fan *et al.* (*1980*), p. 21. Cf. also Eberstein (1974), pp. 142–3.

[61] In particular, there were the contracts by which a landowner leased out his property for mining as well as contracts by which these leaseholdings might be further subleased. We shall see examples below.

The three elements that more than any others tended to characterise the labour-contractor systems were: the leasing by headmen of mining sites from landowners; the exploitation of the mine by one or more headmen or gang bosses, i.e. labour-contractors, who were the real managers of the mine; compensation of all parties by shares in the production of the mine.

(i) *The leasing of mining sites by headmen*

Most of the mines in China, including those worked by career miners, were relatively small-scale.[62] They seldom had more than 100 miners and supporting labourers, and many had fewer than ten.[63]

Ownership of these small-scale mines typically remained in the hands of the owners of the land on which they were found. Ordinarily, however, it was not the landowner who took charge of the exploitation of a deposit.[64] Either because of lack of capital, or a disinclination to become involved in mining, or a lack of the necessary expertise, or some combination of these, landowners typically leased out mining rights on their lands.[65] Often they received a percentage of the output, less often a fixed rent.[66] Sometimes the landowner set up a smelting operation near the mine, requiring the miners to use it to process their ore and collecting a percentage of the final product.

In the case of very small mines, the right to mine might be leased by one or more individuals, each of whom would individually work a part of the deposit. With larger mines however, mining rights would typically be leased to a headman or boss who possessed sufficient capital to organise a larger working for which he would recruit the necessary miners.

(ii) *The rôle of the headman or boss*[67]

For one perspective on the rôle of headmen, we can turn to a legend about the beginnings of mining at Ko-chiu that enjoyed wide currency among Ko-chiu

[62] In this, they were just like most mines even in central Europe right into the early modern period; Nef (1952), p. 476.

[63] Junghann (1911), pp. 11–12. As we have described above (Section (*e*)(1)(ii)), even very large mining complexes, such as the Ko-chiu tin mines, were often broken up into innumerable small claims in order to preserve small-mine patterns of operation.

[64] Only occasionally would a group of landowners pool their capital in order to exploit a mine; Junghann (1911), p. 12. Reluctance to engage actively in mining operations seems to have been common in most mining areas, and not only in China; Hoover & Hoover (1912), p. 82.

[65] Satoi (*1972*), p. 30 views the payment of these rents or lease fees to private landowners as an unwritten law in mining operations.

[66] Sometimes, as at the gold mines in Manchuria early in this century, the owner might not accept a percentage of output (which entailed a certain amount of risk as well as the necessity of keeping informed as to what was going on at the mine) but insisted instead on a fixed payment however well or poorly the mine did; Torgasheff (1930), p. 31. In the prospering 19th century coal mines in Szechwan, property owners attempted to effect a switch from fixed payments (for example, a fee for each worker at the coal face) to percentage rents so that they could share to a greater extent in the prosperity of the mines; an example of the latter would be a fixed fee either in cash or in a certain amount of coal for every 100 loads produced; Zelin (1988), p. 86.

[67] For a detailed discussion of headmen in the Chhing, see Satoi (*1972*), pp. 62–74.

miners.[68] It illustrates the key characteristic of the Ko-chiu deposits: rich as they frequently were, they seldom showed significant surface indications. Prospecting and exploration were thus necessarily haphazard, typically requiring for success either the support of someone with a fair amount of capital or the cooperative efforts of a group of miners.[69] Both coalesce in this story.

According to the legend, the very first successful mining at Ko-chiu was the work of a certain Chao Thien-chueh 趙天爵 who was commonly referred to by the miners as Venerable Ancestor Lord Chao (*Chao lao tsu kung* 趙老祖公).[70] Chao lived in the Khang-hsi period (+1662 to +1722) of the Chhing dynasty. His family originally were natives of Thung-hai hsien 通海縣 (just under 100 km as the crow flies to the northwest of Ko-chiu) but had lived in Ko-chiu for several generations. Chao, however, was the first to try his hand at mining.[71] For 36 years, Chao and his band of miners worked the Sorrowful Family Mine (*Min chia tung* 閔家洞) or, in some accounts, the Indigo Snake Mine (*Lan she tung* 藍蛇洞). During the first 18 years, they encountered only very poor quality ore. Through all of this bad luck, Chao was always as considerate toward his workers as he was abstemious in providing for himself. When the miners ate beancurd, he ate the mash left over after the milk for the beancurd had been drained off. The workers were very moved by his concern and not only admired him but also worked as hard as they could to repay that concern.[72]

Finally, the point came when Chao had pawned just about everything he had of any worth and his resources were exhausted. He suggested to his miners that they try their luck elsewhere but not a one would desert him. Finally, frustrated and depressed, Chao decided one night to sneak off, using for travel expenses a few cash he had accidentally found next to his pillow. Unknown to Chao, his miners had just hit a rich vein.[73] Men were sent out in all directions to try to find him and tell him the good news.

Meanwhile, Chao was passing the temple on Pao-hua 寶華 mountain when he saw a huge snake blocking his path and fainted in fright. It was here that two of the men found him and told him about the strike. Even after he had been shown samples of the ore, Chao was still unconvinced. But they forced him to come back and, after he had examined the workings, Chao discovered to his great joy that it

[68] We have two versions of this legend, one told by Émile Rocher in the late 19th century (Rocher (1879–1880), Vol. 2, pp. 231–2) and which has been summarised, not entirely accurately, in English by E-tu Zen Sun (Sun (1967), p. 57); the other recounted by Su Ju-chiang on the basis of the most common version he heard in 1938 (Su Ju-chiang (*1942*), pp. 15–16, 18). I have followed the much more detailed account in Su, while pointing out some of the major points on which it differs from the Rocher version. The legend is in any case false since the protagonist, Chao Thien-chueh, supposedly appeared on the scene in the Khang-hsi period, when mining was already well established in Ko-chiu. (See above, Section (*e*)(1)(ii).) The major lessons taught by the story, such as the need for perseverance and also for loyalty between headman and miners, are essentially the same in the two versions.

[69] Draper (1931), p. 182. [70] Neither the name nor the title are given by Rocher.

[71] In the Rocher version, the unnamed Chao had amassed a stake from previous mining success and brought his gang to Ko-chiu which, at that time, was a deserted, forested area.

[72] The behaviour of Chao was all the more remarkable because it was accepted that the leaders of mining bands would enjoy certain privileges such as eating better food than the ordinary miners; Sun (1967), p. 57.

[73] In Rocher's more plausible if less dramatic account, the ore was discovered several months after Chao left.

was indeed a major strike. He had the miners continue digging and the more they dug, the richer the ore became. They dug out chunk after large chunk of 'pure ore' (*ching khuang* 淨鑛) and, by the end of the day, the bags in which they hauled the ore to the surface were in tatters. Right in the mine, Chao immediately offered sacrifices of thanks to the 'Dragon King of Ore Veins' (*Khuang Mai Lung Wang* 鑛脈龍王).

The strike made Chao an immensely wealthy man.[74] Later, after he had retired, he had the Pao-hua temple repaired and embellished. When the work was completed in +1714, he installed a figure of the Dragon King and endowed the temple with lands for its support. Chao himself spent most of his time at the temple until his death in the following year.

This legend vividly portrays an ideal of the headman or boss, who was the key figure in those mines where the labour-contract system was used. According to this ideal, a headman was expected to be much more than just someone who assembled a band of miners. It was he who selected a promising mining area, drawing on his prospecting experience and any mineralogical knowledge he might have. He had to have a certain amount of capital not only to meet the costs of recruiting miners but also to provide for the daily needs and perhaps even the tools of the workers at least until the mine began to produce.[75] He had to know mining practice either to direct the miners or at least to supervise one or more foremen. A Yunnan gazetteer succinctly enumerated the abilities he would call into play:

In each gallery, there is one man who searches out the vein leads and examines the colour of the earth; he allocates the hammer-hands [miners] to their jobs (Fig. 125), and determines the direction of the gallery; where the tunnel is of loose earth, he sets up pit-props. As for ventilation, he arranges the bellows; where there is water, he directs the use of drainage; when they find ore, he sets the selling price. Whenever one starts to open a mine, one must first get a timber chief [headman], and if one does get one, the gallery will certainly be successful.[76]

In theory, the obligations of the headman even extended further. He was expected to provide care for those workers who became sick, or a coffin and perhaps even transport back to his native place for a miner who died on the job.

Of course, reality often fell short of this ideal. If Torgasheff's assessment is correct, these obligations were but minimally met, if met at all, by early 20th century headmen.[77] As we shall see in a moment, there was no shortage of headmen whose relationship with the miners under them was highly exploitative. To that extent, the Ko-chiu legend may represent a certain amount of wishful thinking on the part of the miners. Still, it is hard to believe that this story could have enjoyed such wide circulation if the strong ties of loyalty it depicts found no echo at all in the experience of the miners.

[74] In Rocher's version, both Chao and the miners become very rich.

[75] This function was so important that Wong Lin Ken has suggested the term 'advancer' to describe the headmen; Wong Lin Ken (1965), p. 60.

[76] *Hsu Yun-nan Thung Chih [Kao]*, ch. 44, p. 6a; translated in Wright (1984), pp. 45–6.

[77] 'As exceptions, there may be some contractors who regularly take care of their sick or injured men, but this is not a rule.' Torgasheff (1930a), p. 536.

Fig. 125. A mining contractor or foreman distributing tallies (*phai chhou* 排惆 [=籌?]) that assign the miners to specific tasks or areas of work. Since he has some fifty of these tallies, this must have been a mine of some size. This was probably a reasonably effective response to at least part of the problem always faced by the managers of larger mines, namely, exercising some kind of effective supervision over the miners. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 115, pl. 1.

(iii) *Compensation by shares of production*

We have seen that the ordinary practice in the leasing of mines was for the landowner to receive a share of the ore.[78] Miners were occasionally compensated by a daily or monthly wage, or on a piecework basis for certain tasks.[79] Most often, however, they worked for a previously agreed percentage of what the mine produced. For example, if Ku Yen-wu is to be relied upon, it was common in +17th century Yunnan mines for excavated ore to be divided into four equal parts, one each for taxes, expenses, the headman, and the miners.[80] Especially the professionals who participated in the risky work of prospecting and opening up a mine were typically entitled to share compensation, which seems to have been the widely preferred form of compensation among Chinese miners.[81] In 19th century Yunnan, a typical split gave 60 per cent of the profits to the headman while the miners shared 40 per cent.[82]

While one does not find at any time in pre-20th century Chinese mining a major movement toward wage labour that was part of the pioneering rôle that the mining industry played in early modern European industry,[83] working in shifts of a fixed length was probably adopted more easily in Chinese mining because of the long history of dividing the day into a number of 'hours', a practice that did not appear in medieval Europe until about the end of the +13th century.[84]

(iv) *Advantages and disadvantages of labour-contract systems*

The labour-contractor system offered many advantages in the Chinese context. It made possible an organisation of the workplace that reflected important Chinese values. The almost family-type organisation that could grow up when a headman personally recruited a band of miners and took responsibility for them emphasised face-to-face relationships and paternalism. The bond among headman and miners was also frequently reinforced by the fact that they all came from the same native place.[85] The labour-contract system also effectively separated ownership and management, putting the exploitation of the mine into the hands of those with the appropriate expertise. Compensation by shares may have made the miners more open

[78] Since the person who entered into this agreement with the landowner was normally the headman, the word 'tributor' was sometimes used by writers in English to refer to a headman; Tegengren (1920), pp. 19–20.

[79] Eberstein (1974), pp. 143–4; Junghann (1911), p. 48; Brelich (1904); Wong Lin Ken (1965), p. 61; Sun (1967), pp. 55–6. Piecework compensation was especially practical in larger mines which constituted a singularly difficult workplace to supervise continuously.

[80] Ning Chao (*1962a*), pp. 20–1.

[81] Wong Lin Ken (1965), p. 61; Purcell (1965), p. 46. In some Yunnan metal mines, those who participated in the early stages of opening up a mine were referred to as 'close brothers' (*chhin shen ti hsiung* 親身弟兄) and were compensated on a share basis. They were clearly distinguished from those miners who came and went like agricultural labourers and were hired as needed for a monthly wage. These latter were simply 'hired miners' (*chao mu sha ting* 招募砂丁); Wu Chhi-chün (*1845*), ch. 1, pp. 48b–49a; Sun (1967), p. 58.

[82] Wu Chhi-chün (*1845*), ch. 1, pp. 48b–49a. [83] Ludwig (1982), p. 147. [84] *Ibid.*

[85] Torgasheff (1930a), p. 538; Chesneaux (1968), p. 53; Wright (1981a), p. 664. In some cases, especially where mining was strongly seasonal, this even made it possible for a single band to work part of the year as miners, part as agricultural workers; Wright (1981a), p. 658.

to changes that could increase productivity[86] and was probably the most effective way to maximise production in the traditional context.[87] It not only linked compensation to work performed but also held out the possibility of striking it rich. Share compensation also assured that the lion's share of the return would go to those who actually did the work, the headmen and the miners, even if it was the former who often benefited disproportionately.[88] The system was also quite flexible. Mines could grow larger by the simple addition of more bands of miners without significantly increasing the need for complex management structures. This made possible the working of some mines on a scale that would not otherwise have been possible.

Nearly everything about the labour-contractor systems, however, opened the way to exploitation by headmen not hampered by scruples.[89] In the stinging indictment by Herbert Hoover, which undoubtedly includes headmen, 'every deficiency of the [Chinese] workman is multiplied many times by the innate lack of administrative ability in his superiors and their more consummate dishonesty . . .'.[90] Headmen could charge the workers excessively for the living costs they advanced them or for other loans.[91] Indeed, in the versions of the system used among Chinese tin miners in Malaya, the right to provide provisions, necessities and loans *at above market rates* was guaranteed to headmen in their leasing agreements with the landowners.[92] Keeping the miners constantly in debt was a tool used by the headmen to maintain strong control over them. The isolation of many of the mines further increased miners' dependence on the headman and thus their susceptibility to exploitation.

Moreover, the labour-contractor system could be a source of inflexibility as well as flexibility. We have noted the tendency of labour-contractors to hire miners from their native place. As a result, a mine short of labour might have difficulty adding miners if the labour available did not happen to be from the same native places as the headmen operating the mine.[93]

When we examine the effects of the labour-contractor system on technological development, we find the same mixed picture. Functioning at its best, the labour-contractor systems could encourage the use of better technology in at least two major

[86] Chhen Lü-fan *et al.* (*1980*), p. 21; Suhling (1978), p. 145.

[87] There were what might seem to us to be exceptions, however. In the modern perspective, technological efficiency in mining includes maximising the percentage of the desired mineral recovered. In native coal mines, by contrast, contract labourers regularly sought to maximise their compensation by carrying out of the mine only the larger lumps of coal that commanded a premium price, while leaving smaller pieces and dust to serve as fill; di Villa (1919), p. 92. From the Chinese view, however, this was perfectly reasonable given the abundance of coal deposits and the limited market.

[88] Tegengren (1920), pp. 19–20; Chhen Lü-fan *et al.* (*1980*), p. 21; Wong Lin Ken (1965), pp. 61, 219. Torgasheff vividly illustrates the exploitation that occurred in 20th century mines where the headman's agreement with the owners required not the payment of a percentage of output but rather the accomplishing of a specific amount of work and where the miners were paid (generally very poor) wages instead of sharing in the production. Torgasheff (1930a), pp. 533ff.

[89] One might be tempted to see the family-like ties between headman and miners as an important check on such exploitation until one recalls the extent of exploitation, especially of the young and of females, that characterised the traditional Chinese family system.

[90] Hoover (1901–1902), p. 426.

[91] Bain (1933), p. 246. Loans to pay off gambling debts were among the most important, at least early in this century. For borrowing terms among Chinese tin miners in Malaya, cf. Collins (1910–1911), p. 202.

[92] Wong Lin Ken (1965), p. 60. [93] Torgasheff (1930a), p. 538.

ways: (1) It put the management of mines in the hands of those people (headmen or the foremen working under them) who knew the work. Since the share system guaranteed them the lion's share of the profit, headmen were encouraged to maximise production in ways that would increase their profits. That could mean the use of better mining methods; (2) Labour-contractor systems also offered something of an answer to the scarcity of capital that plagued all industry in premodern China. To begin with, agreements under labour-contractor systems regularly arranged a split of capital costs between the mineowners who provided startup costs (buildings, mining and smelting equipment, etc.) and the headmen ('advancers', 'provisioners') who provided the working capital (mainly the basic necessities of the miners, perhaps some tools and loans).[94] Furthermore, the acceptance of the right of subleasing made it possible to supplement the capital of the headmen who were able to bring in further capital to keep the mine going.

Most of the disadvantages of the labour-contractor system in terms of its effect on the technology used stemmed from the fragmentation it introduced into mining operations and from the conduct of the headmen. As we noted, even the largest mines were usually worked as a conglomeration of small workings, each in the hands of a headman and his band of workers.[95] With the mine thus parcelled out to small, independent groups of miners, the mining was usually carried on with the simplest, small-scale techniques.[96] Moreover, the separate bands of miners worked to a large extent in competition with one another. This probably inhibited the most effective exploitation of large ore deposits. Each band of miners acted to maximise its own return, with no one considering the best overall exploitation of the deposit. If in mining, 'a bad beginning means a bad end', the labour-contractor systems not only led to innumerable bad beginnings but also assured bad decisions throughout the mining process. As Torgasheff complains of the headmen: '. . . by their irrational operations not a few Chinese mines have been ruined for good.'[97] Indeed, one can make the case that the labour-contractors bore a major responsibility for the technological backwardness of so much of Chinese mining (as well as the dreadful conditions under which it was carried on.) Certainly, if we are justified in extrapolating 20th century descriptions of headmen back into earlier periods – and to some extent that is probably justified – we will hardly be tempted to idealise their contribution to the mining endeavour. Many of the headmen unflinchingly sought to maximise their own profits, to the detriment of any other considerations.[98] At least among Westerners, their exploitation of the miners they controlled was legendary. Moreover, not all

[94] Wong Lin Ken (1965), pp. 60–3.

[95] On occasion, one headman might have as many as 100 miners in his band (Imahori (*1961*), p. 393) but ordinarily the group would be much smaller, probably closer to 10 or 15 miners.

[96] Thus, even in China's modern coal mines early in this century, mechanisation of coal cutting was inhibited by the organisation of the mines through labour contract systems; Wright (1984), p. 40.

[97] Torgasheff (1930a), p. 534.

[98] For example, as Tim Wright suggests, the fact that even in partially modernised coal mines early in this century labour contractors controlled much of the haulage probably inhibited even modest efforts at mechanisation (though relative factor costs – cheap labour vs. expensive capital – were probably a more important determinant); Wright (1984), p. 41.

of them by any means possessed the expertise to direct mining operations effectively. After all, the qualities and talent that went into the making of a successful labour recruiter were not necessarily those that produced a first-rate, or even a competent, mining boss.[99] Even when the headmen possessed the necessary knowledge, expertise and familiarity with the best technology and the best methods, their greed for immediate personal profit might still lead them to what was usually the most reliable way of maximising profits: greater exploitation of the workers.

(4) Impact of Miners' Beliefs and Values on Mining Technology

'No incense, no mine' (*wu hsiang, pu chheng chhang* 無香不成廠)

Yunnan miners' proverb[100]

Most mines are haunted; it is only a question of degree. The scoffers have their answers, and sometimes they may be right, but a residue of experience remains, involving the most sober and matter-of-fact of men, which defies rational explanation.

Tom Morrison[101]

Technological innovation can have one or more of several goals: increase in total production or the speed of production, reduction of labour costs, making work easier, accomplishing tasks that would be impossible without the improved technology, a more standardised product. There was much in the value system of the Chinese miners, however, that greatly inhibited the introduction of new techniques.

Ranking high in this value scheme was a general conservatism and disinclination to change long-standing ways of doing things. Technological conservatism is reflected in the very first surviving written work in Chinese that deals extensively with handicrafts: the *Khao Kung Chi* 考工記 (The Artificer's Record) section of the *Chou Li* 周禮 (Rites of Chou). It makes a clear distinction between the *chih-che* 知者 or sages who at an early time invented things and the *chhiao-che* 巧者 or skilled craftsmen who came later and whose job it was not to improve things but to preserve them and pass them on.[102] The reluctance to adopt even seemingly simple changes in working practices was often noted in recent times by Westerners who were engaged in introducing modern mining methods into China. For example, Thomas Webster, writing about the famous north China Kaiping 開平 coal mine, noted that even after tubs for transporting coal were introduced at the working face, '[t]he old method of using baskets was given up with great reluctance; even when the tub was close to the face they persisted in filling the coal into baskets, which in turn were emptied into the tubs.'[103]

[99] Nor an amenable one, as foreign businessmen in China found out. H. Foster Bain summarises the situation: 'The contract system makes it easy for a foreigner to do business in China as long as he is content to do it on the contractor's terms. If he has his own ideas as to times, seasons, speed of work, and similar matters, he will have great difficulty.' Bain (1933), p. 246. Today's foreign businessmen in China may be excused for feeling that not much has changed.

[100] Yen Chung-phing (*1957*), p. 55.

[101] Morrison (1992), p. 240.

[102] Yoshida (1979), p. 50. On the origins of this work, see Hsuan Chao-chhi (*1993*).

[103] Webster (1900), p. 697.

Often, however, this conservatism made good sense given the social environment of the Chinese miners. Warden A. Moller, like Webster familiar especially with the introduction of new coal mining technology into northeastern China, commented on how difficult it was to motivate the Chinese miners to work faster. Higher compensation would not work because so many of them simply preferred to earn just enough to get by and would therefore simply work a shorter period at the higher wages in order to obtain the same amount.[104] But he perceived at least two good reasons for this attitude: the general insecurity of personal property that made accumulated goods a target of robbers or even official squeeze, and the ease with which poorer or lazier family members could attach themselves to their better-off relations in bad times, thus precluding the need to plan for a rainy day.[105] One would not want to overgeneralise such motivations but there can be little doubt that they were operative at least sometimes, and perhaps even quite often.

The economic environment also encouraged a conservative attitude toward technological innovation. In an economy marked by an abundance of labour, there could hardly have been much enthusiasm among the miners for 'improved' technologies or working patterns that promised a saving of labour. Thus another on-the-scene commentator at the turn of the century could speak of the general Chinese worker's 'dread of displacing manual labour and his baseless (*sic*!) fear of depriving his fellow man of work'.[106] Those who ran the mines could often take advantage of this glut of workers, effectively substituting cheap labour for investment in technology.

It was perhaps this existence of abundant, cheap labour more than anything else that was the chief impediment to technological advance in Chinese mining. When combined with other factors inhibiting capital investment (cost of transportation, limited markets, irregular deposits that precluded working by modern methods), it assured that the most economical answer to almost any mining challenge would be sought in greater or more effective input of labour. More astute Western observers in the 19th and early 20th century saw this very clearly. For example, one mining engineer noted that cheap labour made the digging of exploration shafts a better way of exploring a deposit than the use of what would ordinarily be seen as the more advanced technique of borehole drilling: 'When prospecting a placer, if possible, sink shafts instead of drilling holes. In this country, labour is very cheap, whereas the cost of imported machinery is very high; less dependence can be placed on the result of a drill hole in regard to physical conditions and the probable gold, tin or platinum content than in the case of shafts.'[107]

[104] Moller (1902–1903), p. 143. Others made similar comments; cf. Seltzer (1910), p. 547. Hollister-Short suggests (personal communication), that the ideas of consumerism and prudential savings that motivate so much of the striving for higher incomes in the modern world 'are bourgeois notions imposed on everyone else as that class became politically and culturally ascendant.' There is much truth in this so long as we do not ignore that the desire for nice things (or, among the poor, greater access to necessities) and even a certain amount of 'prudential saving' by those who were able to do so were hardly absent at least in premodern China.

[105] Moller (1902–1903), p. 143. On the first reason, see also Read (1907), p. 1297; on the second, Bain (1933), pp. 242–3, but also the qualifications about the amount of help that could be expected; Perkins (1975), pp. 13–14.

[106] Parsons (1900), p. 491. On this point, see also Elvin (1975), pp. 108–9; Bain (1933), p. 245.

[107] di Villa (1919), pp. 19–20.

Fig. 126. Making an offering to the spirit of a mountain said to contain coal. Anonymous album, c. mid-19th century. Bibliothèque Nationale, Paris: Oe 117, pl. 1.

The religious beliefs and superstitions that were so pervasive among the miners were also a hindrance to greater 'rationalisation' of traditional mining practices and to the creation of a modern workforce.[108] There appears to have been a widespread propensity among the miners to attribute virtually everything having to do with the success or failure of a mining venture to the actions of spirits. The appearance, quality and pinching out of ore deposits; the presence or absence of water; cave-ins, poisonous gases and accidents of all kinds: all were seen as the work of spirits and forces that one tried ideally to win over but at the very least not to offend.

One way of getting on the right side of the spirits was through the offerings and sacrifices that were frequently to be seen in and around the mines (Fig. 126).[109]

108 From the evidence presented below, it will be clear why we are unable to accept Elvin's generalisation that: 'Superstition seems to have had no inhibiting effect on economic enterprise, with the exception of geomantic objections to mining.' Elvin (1975), p. 109.

109 Pai Shou-i (*1960*), p. 987. Yen Chung-phing (*1957*, p. 55) has suggested that the risk of mining, at least in Yunnan, was significantly increased by the cost of temples and sacrifices to the spirits in whose hands all success in mining lay. It seems doubtful, however, that religious expenditures were really so significant when measured against the production of the mines.

It was no accident that one of the first things Rocher noted as he approached the Ko-chiu tin mines in the late 19th century was the proliferation of elaborate and well-maintained temples on the mountainsides with their well-cared-for goats destined for sacrifices to the spirits.[110]

Observing verbal taboos (*hui* 諱) was another precaution taken to avoid inviting bad luck. Miners in Yunnan, instead of using for 'rock' the normal word *shih* 石, which was a homophone for *shih* 失 'lose', used *hsia* 峽 'gorge' instead; in the same way, *huang* 塃 (the word for 'wasteland' with the earth radical added) was used to replace *thu* 土 'earth' which had the inauspicious homophone *thu* 吐 which could also have the connotation of 'reject', 'cast aside'. Even the world 'good' (*hao* 好) was replaced by *chhe* 徹 'penetrating' so as to avoid the homophone *hao* 耗 meaning 'exhausted' or 'used up'. Miners surnamed Meng 孟 commonly changed it to Hun 混 in order to avoid the suggestion of *meng* 夢 'dream' and the possibility that the ore deposits might prove as unreal (or fleeting) as a dream.[111] Sometimes, no words were best. For fear that even the mention of food might lead to there not being enough, hand signals without any words were used to call the miners to eat.[112]

There were also actions to be avoided. For example, it was bad luck for anyone wearing an object of gold (or metal?) to enter a mine. And since, in Yunnan mines at least, ore veins were considered to be divine dragons averse to officials, no one with an official position was permitted entry into a mine![113]

As we have noted above, geomantic considerations were one of the techniques used by Chinese prospectors (Fig. 127).[114] Geomancy could also play a rôle in determining where mining might or might not be carried on. Since it was mainly officials who sometimes for supposedly geomantic reasons prohibited mining in a given area, we shall return to this question in the following section. Here we might note, however, that geomancy could also operate more indirectly to influence mining. At Ko-chiu, there was a story widely told about how the whole prosperity of Ko-chiu went back ultimately to the statement of a geomancer (*ti shih* 地師).[115] According to this story, which went by the title 'First excavated Old City Gate shaft, afterwards opened up forty eight mines' (*hsien ta lao chheng men tung, hou khai ssu-shih-pa chhang* 先打老城門洞，後開四十八廠), a family in which someone had died called in a geomancer to determine an auspicious site for the grave. The geomancer found a remarkably good site near Yellow Thatch Mountain (*Huang Mao shan* 黃茅山) and told the head of the family: 'If you bury the body here, you can bring prosperity to your family. If you leave this place for another use, it will bring riches to the entire district.' The household head, being a very unselfish man and strongly believing

110 Rocher (1879–1880), Vol. 1, pp. 236–8. Stories were told also of miners who resorted to drastic measures against the ghosts of dead miners, effectively killing them a second time so that they could not spread evils among the living miners; Eberstein (1974), p. 204, citing a story told by Yuan Mei 袁枚, the +18th century literary luminary.

111 Wu Chhi-chün (*1845*), ch. 1, pp. 31b–32a; Chhen Lü-fan (*1980*), p. 38; Sun (1967), p. 66; Yen Chung-phing (*1957*), p. 55. For several other examples, cf. Su Ju-chiang (*1942*), p. 16.

112 Su Ju-chiang (*1942*), p. 16. Or bamboo tallies: see Fig. 2.

113 Wu Chhi-chün (*1845*), ch. 1, p. 31a; Su Ju-chiang (*1942*), p. 16; Sun (1967), p. 66.

114 Section (*f*)(3).

115 The story is related in Su Ju-chiang (*1942*), p. 15.

Fig. 127. Geomancers at the Thao-hua 桃花 gold mines in Kwangsi. The third and fifth figures from the left are two geomancers who work together and are much consulted by the miners (who are also happy to get more scientific advice from geologists). Original photo, 1994.

the words of the geomancer, had the body buried elsewhere. Some time afterward, people came and opened a mine on the site. They discovered very rich ore and this became the famous Old City Gate shaft, the first underground mine at Ko-chiu. Later, mines were opened up one after another. Thus the prosperity of Ko-chiu was ultimately all due to the words of a geomancer.

It is, of course, difficult to assess how strongly miners were influenced by geomantic considerations, especially where they would have precluded mining in what looked like a promising area.[116] There are numerous examples to suggest that such considerations were of relatively minor importance. In Taiwan during the Chhing period, it was largely the local gentry who appealed to geomantic ideas when petitioning the government to prohibit the spread of private coal mining by miners who appear to have been more encouraged by an expanding market than discouraged by any fear of geomantic violations.[117] In certain areas of southern Hunan, officials used geomantic arguments to prevent coal mining until a shortage of firewood led to a lifting of the ban in the +18th century, after which coal mining thrived right down to this century.[118] We also have examples of other cases unrelated to mining where geomancy was used as a smokescreen, as in the +15th century campaign against

[116] Cf. the comments of von Richthofen in Section (*l*)(2) below and Eberstein (1974), p. 203.

[117] Huang Chia-mo (*1961*), pp. 1, 3. [118] Li Hua (*1990*), p. 48.

extension of the Grand Canal waged by those with an interest in hauling and porterage.[119] On the other hand, it is quite likely that geomantic concerns carried more weight for the populace at large who did not have an economic stake in mining.[120] There were certainly at least occasional cases where generalised local opposition of this sort, perhaps encouraged by the gentry, hindered or prevented mining.[121]

The main focus of geomancy as it related to mining was the concern that mining operations might unleash subterranean forces that would disturb the peace of graves in the area.[122] Very likely even more influential among the miners was the reluctance to directly disturb graves in the course of excavations. Yet this was hardly an insuperable obstacle to mining. While it may occasionally have inhibited prospecting, most mines were located in out-of-the-way areas unlikely to be the site of graveyards. If a valuable deposit were found in an area containing graves, they could usually be moved at a modest cost in labour and in permission fees to family members of the deceased.[123] As Thomas Read concluded, 'it is but seldom that a regard for 'spirits' is allowed to operate to financial disadvantage.'[124]

The lack of a body of mining literature by or for miners (who were overwhelmingly illiterate) must have made them especially susceptible to myths that often substituted for the hard, generalised mining knowledge so difficult to acquire without the help of the written word.[125] Their religious beliefs also dovetailed with a fatalism that formed an integral part of their worldview. Injury or death by accident in the mines was assumed to be a punishment from the spirits for past misconduct. Rocher recounts an incident that he witnessed personally: a miner in his twenties was urged on by his comrades who had discovered a rich deposit, but at a depth where breathing was very difficult. Before he could get out with his ore, however, he passed out for lack of air. That evening, his comrades noticed that he had not returned but, instead of organising a rescue effort, they waited until the next day when they recovered his body. The explanation given to Rocher was: 'If he has had an accident, it is without question because he has offended the spirit of the mountain or because he has committed some evil act or stolen from his comrades. Heaven, in its just anger, strikes down only the guilty. If the punishment is terrible, it is only because they have merited it.'[126] Western observers in China in the 19th and early 20th century were often

[119] Elvin (1975), p. 109. [120] Nishizawa (1913–1914), pp. 898, 937.

[121] Williamson (1867), p. 66. [122] Eberstein (1974), p. 203.

[123] On the other hand, the Emperor Khang Hsi 康熙's 'Sacred Edict' forbade destruction or removal of remains of grandparents or parents 'through belief in the sinister statements of geomancers'. See Freedman (1979), p. 316, fn. c.

[124] Read (1912), p. 4. See also Williamson (1867), p. 56; Collins (1922), p. 40; Freedman (1979), pp. 320–1.

[125] These myths need not be especially 'religious'. For a long list of non-religious mining myths that had some currency among miners in the western United States (e.g. ore deposits usually increase in value at greater depths, veins widen below their outcrops, valuable deposits are typically marked by prominent outcrops), see Pearl (1973), pp. 275–7 and also Young (1970), p. 9. The combination of a lack of a mining literature in China together with the great variety of ore deposits must have made it especially difficult to put to rest a myth once it had gained some acceptance among miners.

[126] Rocher (1879–1880), Vol. 1, p. 244. In a chilling comment that calls to mind thought control techniques used in the People's Republic of China, Rocher notes: 'Therefore, instead of deploring the fate of these unfortunates, they dissect their past, review their failings, comment on them, exaggerate them. Before long, legend will attribute the most extraordinary things to them.'

struck by the fatalism of Chinese miners. Warden A. Moller provides a striking example from a coal mine in northeast China:[127]

> [Chinese workmen] have an almost frightful indifference to life and danger. In one case, where six men were burnt, through one of them smoking on the rise side of an end-stall, the men working on the dip side hardly turned round, and had to be forced to leave their work to help in carrying out the burnt men. The man's comrades saw him smoking, and did nothing to prevent it, although they were fully aware of the danger.

Such fatalism could inhibit if not preclude even the simplest measures to improve mining practices, even those relating to the safety of the miners.[128]

It is not difficult to see how many of the miners' beliefs had a real social utility. Many foreign observers emphasised the rarity of those petty crimes and pilfering that one would ordinarily expect in mines where large numbers of miners worked in relatively close proximity to each other. Rocher attributes it to a universal conviction among the miners that the 'hook-hearted' person (*kou hsin tzu* 勾心子) would inevitably suffer an accident. Thus, miners could pile up their ore and leave it unattended in perfect confidence that no one would dare to steal from it.[129] On the other hand, one should guard against over-idealising the beneficent effects of religious beliefs. Mining camps were usually, in China as elsewhere, rough places. There is plenty of evidence, for example, that robbery, fighting and homicide were common occurrences in the Yunnan copper mines during the Chhing[130] and we know that many mercury miners in Kweichow early in this century lived in the mines out of fear that their ore would be stolen if it was left unguarded.[131]

Overall, however, religious beliefs and superstitions served to hinder sound and effective mining practices. As late as the early years of this century, the authorities prohibited the use of dynamite in bad years (?) for fear that it might disturb the spirits of the mines.[132] Even rocks that could have been removed either by explosive or by non-explosive methods were sometimes inconveniently left in place because, according to the miners, any efforts to remove them generated groaning or other terrifying sounds that indicated the displeasure of the spirit of the mountain.[133]

The most important result of the pervasive belief in the decisive rôle of spirits, however, was that the hit-or-miss, risky element of mining was for Chinese miners not just an inevitable *part* of the mining enterprise but became in their minds the single, overriding, universal characteristic of mining. Against this belief, any efforts to build up a rational, experience-based body of practical mining knowledge had always to compete against these essentially anti-rational convictions. Progress in this area was bound to be slow.

[127] Moller (1902–1903), p. 144. Inkeles & Smith (1974, p. 113) see the belief that 'prevention of accidents is more a matter of carefulness than luck' as a characteristic of the thinking of more 'modern' individuals.

[128] Shansi coal miners, for example, left out millet to feed the rats in the mines on the belief that they would provide warning of an impending accident; Shockley (1904), p. 862.

[129] Rocher (1879–1880), Vol. 1, pp. 244–5; Collins (1909–1910), p. 190.

[130] Vogel (1987a), V.2. [131] Brelich (1904), p. 485.

[132] Anon. (1926), p. 154; Jarland (1921), p. 375. Firecrackers were, of course, something different – a generally accepted method inside and outside of mines for driving off evil spirits; Hoover (1901–1902), p. 427.

[133] Rocher (1879–1880), Vol. 1, p. 245.

Even when Westerners began in the last century to demonstrate the effectiveness of modern mining practices to Chinese miners, the miners sometimes simply modified or broadened old ways of thought to interpret what they saw. They might even attribute to Westerners special powers of a kind that had previously been a monopoly of the spirits. A good example is the reaction of the Ko-chiu miners in the late 1800s as they came to realise that Europeans surpassed them in the ability to discover and assess deposits. Instead of attributing this skill to a better understanding of geology and mineralogy, they explained it by a supposed ability of the Europeans to see 2 metres underground, a distance that could be extended when necessary by using the canes that they carried with them![134]

(5) The Shortage of Capital

> ... any society, at any time, commands more potential for technological innovation than it can ever hope to exploit. *George Basalla*[135]

There is relatively abundant evidence to show that, over the past millennium at least, mining in China regularly suffered from a shortage of private investment capital.[136] In extreme cases, a considerable diversion of available, liquid capital to fuel a mining boom was capable of rapidly producing a shortage of coinage in other areas of the economy.[137] Even the requests that one frequently reads asking the court to allow the closing of mines because the deposits had been worked out often disguised the fact that the copper producers had run out of capital.[138]

Though pooling of private capital sometimes sufficed especially to meet specific technical problems such as drainage,[139] it was the government that in many cases had to assume the rôle of capital provider of last resort, as it were, in order to encourage the opening or the continued working of mines.[140] This was a prominent part of state

[134] Rocher (1879–1880), Vol. 1, p. 240. On the other hand, the Chinese miners were perfectly capable, at least sometimes, in detecting incompetence or fraud on the part of foreign 'experts' brought to China to help develop modern mines. V. K. Ting recounts the story of the Commissioner of Mines in Yunnan who, in the late 1880s, invited some Japanese engineers to help develop copper mines in that province. The miners were at first impressed by the Japanese claims that they could see through rocks with their telescope and compass and discover hidden ore. After more than a year in which no copper was found, the miners became suspicious. As Ting recounts it, the miners 'to verify their suspicion, ... buried a large mass of copper ore immediately below the opening of the shaft. Then the Japanese were asked to inspect the spot with their telescope and compass to see if any ore were there. On receiving a negative answer, shouts of laughter and contempt greeted the supposed experts, and the ore was dug up in their presence. This seemed to satisfy the Commissioner that the Japanese were imposters and they were dismissed accordingly ...'; Ting (1915), pp. 208–9.

[135] Basalla (1988), p. viii. Translated to the case of mining, one can make the point that, in two societies with equal mining and metallurgical knowledge, the society with better means of mobilising capital will often be able to exploit deposits that would remain unexpoitable in the other society. See Bronson (1993), p. 69.

[136] Vogel (1987a), I.2. [137] Satoi (*1972*), p. 38.

[138] Sun (1964), p. 72; Pheng Yü-hsin (*1984*), p. 81. Alternatively, the problem could be that the miners could no longer make economic sense out of mining, given the ground-rules established by the government (above all the price it was willing to pay for e.g. copper).

[139] Lü Tai-ming (*1986*), p. 165; Cartier (1967), p. 64.

[140] Mining thus relied much more on government capital in China than, for example, in early modern Europe; Vogel & Theisen-Vogel (1991), p. 29.

mining policy at least since the Sung.[141] A particularly striking example showing government effectiveness in this area is to be seen in the development and maintenance at a high level of production of the copper mines of Yunnan during the +18th and early 19th centuries.[142] On the other hand, limited availability of both public and private capital was a major impediment to the modernisation of the Chinese mining industry in the 19th and 20th centuries.[143]

In attempting to account for the general scarcity of significant private capital investment for mining, we do not get very far by postulating a general absence of capital for investment. At least since the +11th century, Chinese with even quite modest resources for investment had shown themselves quite able to form sophisticated partnerships in order to generate substantial investment funds.[144] Thanks to the researches of Teng Tho 鄧拓, we have a detailed picture of the use of such partnerships in the +16th to +18th centuries to pool capital for investment in the coal mines at Men-thou-kou 門頭溝, some 25–30 km west of Peking.[145] Provided an opportunity was seen as sufficiently attractive, mining capital could flow in from an area much larger than one might expect. In the early Chhing, for example, the government decision to establish a fixed 20 per cent tax rate on copper production in Yunnan and to allow free sale of the remaining production attracted merchant investment capital from all over south China. Basing himself on mining tax revenue figures, Yen Chung-phing 嚴中平 estimates that Yunnan copper production rose twenty times in the twenty-one years between 1685 and 1706![146] As Madeleine Zelin argues, '... where potential profits were deemed sufficiently large, institutional mechanisms could be developed to overcome the weaknesses in Chinese capital markets.'[147] It seems abundantly clear that, where there was a shortage of investment capital for mines, it derived from the decision by investors that the potential return on an investment in mining, except under very special circumstances, could not begin to outweigh the risks or other negatives that argued against such an investment.

We have discussed in the introduction some of the implications of the riskiness of mining as an economic activity.[148] Potential investors had to consider whether a

141 Golas (1989), pp. 412, 420. 142 Vogel (1987a), I.2; Lee (1987), chap. 7.

143 Read (1920), p. 301; Collins (1909–1910).

144 Shiba (*1968*), pp. 451–66, translated in Elvin (1970), pp. 196–201. For a detailed discussion of many of the models for assembling and investing capital that were available by the late imperial period, see Zelin (1988). For a +1735 contract from the Men-thou-kou coalfield providing for the establishment of and association or partnership (*phi-huo* 批夥) to exploit the mines in common, see Teng Tho (*1956*), p. 12; Cartier (1967), pp. 64–5.

145 Teng Tho (*1956*); critiqued in Thang Ming-sui *et al.* (*1958*); abbreviated translation with corrections from Thang *el al.* in Cartier (1967). Pooling existing capital made all the more sense because of the cost of borrowed capital in this area: in +1779, the rate of interest was a staggering 30% *per month*! Cartier (1967), pp. 64–5; 77; 78.

146 Yen Chung-phing (*1957*), p. 6. This estimate is accepted by Pheng Yü-hsin (*1984*, p. 81) though Vogel (*1987a*), V.1) is less sanguine about the rise in production totals during this period.

147 Zelin (1988), p. 79. See also Wright (1981), pp. 322–4 which makes the same point for coal mining and the extensive discussion of various forms of mining capital in Satoi (*1972*).

148 In the late imperial period, precisely when mining advanced so dramatically in Europe, it is likely that centuries of intensive exploitation of deposits in many areas of China had left only relatively poorer, less accessible and generally unattractive or uneconomic deposits still to be exploited, thus racheting up the inevitable riskiness of mining. The great exception, of course, was Yunnan, where intensive mining activity began only in the Ming.

workable deposit would be discovered or whether a known deposit could be worked so that they could not only recoup their original investment reasonably expeditiously but also obtain a return on that investment in the form of profit.[149] The risk was all the greater and more unpredictable because, as in early modern Europe, investors were liable to be called on to supply additional capital when their original investments were insufficient, either because they clearly were unable to provide at the beginning of the operation all the capital needed, or because expenses turned out to be larger than expected.[150]

The government could afford to be somewhat more liberal. In certain circumstances such as the lending of capital at copper mines, it might be satisfied if it could obtain the copper it needed and not lose money. But even this lesser standard was by no means always easy to meet. The famous late Ming official, Hai Jui 海瑞, opposed the opening of mines in Chekiang in part because he estimated that administrative costs would outrun by ten times any profit to be made from them.[151]

All risk derives from the unknown; knowledge and understanding are thus key tools for coping with it. One can mitigate risk by fully understanding its ramifications. But sound understanding of mining was very limited even among miners; it was for the most part non-existent in the rest of the society, including among potential investors.[152] In such circumstances, investors were strongly tempted to rely on another risk minimisation strategy by demanding a very rapid return of at least their original investment. This strategy was certainly typical of mining investors in China around the turn of this century.[153] The long odds against rapid returns under the conditions of traditional mining must usually have precluded this option.

An alternative strategy sought not to minimise risk but rather to seek compensation for it in a very high rate of return on investment. In the context of traditional Chinese mining, however, one would have to be very optimistic indeed to anticipate such returns. For one thing, traditional mining offered abundant opportunity and temptation for those at the mining site to steal ore, falsify books, and engage in other surreptitious practices, all of which robbed investors of their returns.[154] Moreover, few mining operations of any size were likely to get started without the approval and at least tacit cooperation of the officials. Such approval came only at a cost, sometimes a very significant one. If the operations should prove successful, it was entirely

[149] This attitude carried over into the first decades of this century, as described by Nishizawa Kimio: 'It is the established custom in [China] that a new company must pay dividends to its shareholders from the first year of its existence, and this forms invariably a clause of the articles of association. Some concerns which have failed to realise a profit have to contract a high interest loan in order to pay dividends in full.' Nishizawa (1913–1914), p. 903.

[150] Nef (1957), p. 476. In some cases, it was probably determined explicitly at the outset that investors would be called upon for monthly payments to meet running expenses until the mine had become profitable, as we know was the practice at the Fu-jung 富榮 salt yard in Szechwan; Zelin (1988), pp. 99–100. In this same article (pp. 84–5), however, Zelin suggests that, at least in some areas by the 19th century, an added increment of security was enjoyed by mining entrepreneurs because of an increasing separation of mineral/mining rights and land rights.

[151] Cartier (1973), pp. 149–50.

[152] Read (1920), p. 301; Yen Chung-phing (*1957*), p. 56; Shih Kuo-heng (1947), p. 56.

[153] Brelich (1904), p. 487; Hoover (1899–1900), p. 325.

[154] Shih Kuo-heng (1947), p. 56; Nyström (1912), p. 86.

predictable that the formal or informal demands of the officials would escalate, though it was highly unpredictable by how much![155] The best chance of avoiding the notice and interference of officials was to keep operations as small and unobtrusive as possible.[156] To the extent that this option was chosen, the need for mining investment was reduced, as was the possible return on investment.

Investors also had to weigh the risk/return ratio of mining investments against the possibilities in other forms of investment. Simple money-lending was ordinarily at least as lucrative, and a good deal less risky, than investment in mining. For example, in the early decades of this century, before the arrival of modern banks, the native money shops (*kho hao* 客號) at Ko-chiu charged as much as 4.5 per cent a month to borrow money.[157] Rather than directly investing in mines, some investors found it more attractive to lend money to the mining headmen, though the risk of default here could be considerable.[158] Moreover, abundant opportunities for investment were available in other areas of trade or finance (which did not carry the same stigma as mining), not to speak of 'investments' in culture that brought their own rewards if not in money then certainly in status. Across China, such investments tended to be more attractive to wealthy merchants than investments in any kinds of industrial enterprises, above all mining.[159]

There were thus plentiful reasons why significant amounts of private investment capital was generally in short supply in traditional mining. It does not automatically follow, however, that the shortage of mining capital was the major brake, or even *a* major brake, on improvements in mining technology, at least before the 19th century. We have stressed above that small-scale operations using very simple technology were the norm in traditional Chinese mining. Such operations could be relatively easily brought on line using either the funds accumulated by headmen[160] or by contributions (*tan fen* 石分) from all the miners in a working group whereby they acquired the right to a share of the profits (*hung chang* 洪賬) based on how much they had contributed in money and in work.[161] Even those mining centres with high levels of production tended to be divided into many small, independent workings, as at Ko-chiu with its 1,000+ tin mines spread over some 1,150 square km[162] or in Shansi where the largest coal deposits in the world were worked by means of innumerable small mines[163] or in Yunnan copper mines where single 'mines' might be divided

155 Anon (1861), p. 207; Eberstein (1974), pp. 191–3; Williamson (1867), p. 67; Satoi (*1972*), p. 68. One can hardly overstate here the contrast with European mining in the early modern period with its well-established mining law *that even government authorities felt obliged to observe*; see the discussion below, Section (*l*)(2).

156 Dawes (1891), p. 335. 157 Su Ju-chiang (*1942*), p. 13. 158 Dawes (1891), p. 335.

159 Vogel (1987a), I.2. There were of course exceptions. In the +17th and +18th centuries, Yunnan was a magnet to rich merchants from all over south China who came to invest in mining operations there; Chang Yü-jung (*1963*), p. 38. Even in this case, however, it was only the richest of these merchants who could assemble as much as two or three years working capital in advance; Lee (1987), p. 209. Nevertheless, the general Chinese view toward mining investment, especially in the most recent centuries for which we have better evidence than earlier, contrasts dramatically with the positive attitudes toward this kind of investing that prevailed in central Europe in the late +15th and in the +16th centuries; Suhling (1977), esp. p. 575.

160 See above, Section (*k*)(3)(ii).

161 Pheng Yü-hsin (*1984*), p. 79. Pheng explains *tan fen* as 担[擔]份 'burden shares'.

162 Shih Kuo-heng (1947), p. 53. 163 von Richthofen (1907), p. 498.

into as many as 40 or 50 separate and independent workings.[164] It was an organisation of production that served to minimise the need for capital investment because it relied on maximum use of plentiful low-cost labour.[165] Many an early attempt to introduce modern machinery into Chinese mines floundered on the failure to understand that, in the Chinese context, more advanced technology and large-scale operations did not always add up to economic efficiency.[166] As Maxwell Steward, writing as late as 1930, noted: 'There are still many aspects of mining in which hand labour is more economical than machine work, and for the time being the engineer must carefully study the problem lest in his zeal for modernization, the cost of production be made unduly high.'[167]

Given the decentralised, labour-intensive character of most Chinese mining, the small capital needs of even larger workings could normally be met at least in a minimal fashion by the headmen who do indeed seem to have been the most prevalent providers of capital for the opening and working of mines.[168] But most of their very limited amounts of capital seem to have gone mainly to subsidise the living costs of the miners in their group.[169] Except in rare cases of an especially lucky strike, even those headmen who proved particularly adept at exploiting the miners they controlled were unlikely to accumulate amounts of capital that would have enabled them to increase significantly the scale of the workings they operated. And in those exceptional cases where headmen disposed of more substantial capital, it was typically a more logical choice to expand the scope of operations by adding low-cost labour rather than attempting to introduce improved (but more expensive) technology.

Contemporary figures comparing investment levels in traditional vs. modern mines are rare. We do have a very telling example from tin mining, however. Wong Lin-ken in his study of late 19th century tin mining carried on by Chinese miners in Malaya notes that: 'In 1880, the capital cost of opening a mine worked by 600 labourers, with no Western machinery, and a productive life span of five years, was estimated at $4,272 or about the cost of a Gwynne centrifugal steam pump.'[170] At China's major tin-producing centre, Ko-chiu, even the largest mines had far fewer than 600 labourers.[171] If roughly similar costs prevailed at Ko-chiu, initial capital

[164] *Hsu Yun-nan Thung Chih [Kao]*, ch. 44; Kuo Yun-ching (*1984*), p. 235.

[165] Lee (1987), Chap. 7. Centres like Ko-chiu also often benefited from especially favourable natural conditions such as rich and easy-to-work deposits or absence of mine waters, all of which encouraged small-scale workings that hardly required the use of advanced technology; Collins (1909–1910), p. 190. Cf. also the discussion above in Section (*e*)(1)(ii)(δ).

[166] King (1965), p. 236; Wong Lin Ken (1965), p. 236. It is worth remembering here that it is still very uncertain how many of the very numerous innovations in European mining from the +14th to the +17th centuries actually brought real technical advance and greater levels of productivity; Molenda (1988), pp. 81–3.

[167] Stewart (1930), p. 891.

[168] An interesting example of the modest amounts of capital normally needed is provided by the well-documented Men-thou-kou coal mines west of Peking in the Chhing. Accounts there were kept in terms of coins and strings of coins, though throughout the economy silver was in regular use for large transactions; Cartier (1967), p. 62.

[169] A suggestive example is provided by the +18th century headmen entrepreneurs in Yunnan who made the rounds of households that had a surplus of rice and offered to exchange shares in their new mining venture for contributions of rice; cf. below, Section (*l*)(2).

[170] Wong Lin-Ken (1965), p. 63. [171] Su Ju-chiang (*1942*), pp. 19–20.

costs for opening even a large-scale mine using native techniques would have been much less than the price of a single steam pump. Moreover, besides its initial cost, the steam pump would have brought with it regular maintenance costs as well as the costs of repairs and spare parts.[172] Finally, when a mine failed, it was easy to disband labourers while any machinery that had been introduced might well represent a significant capital loss.[173]

[172] Nyström (1912), pp. 86–7; Vogel (1991d), p. 116. [173] Shih Kuo-heng (1947), p. 59.

(*l*) THE STATE AND MINING TECHNOLOGY

Under the last Dynasty gold mining produced a certain amount of revenue, but as time went on the financial strength of the people failed, with the result that there was much suffering in the gold mining districts. Continued mining must sooner or later exhaust the country's mineral resources. Mining officials do not report exhaustion of the deposits, and insist on undiminished taxation. Consequently, however benevolent my intentions may be, hardships are unwillingly inflicted upon my people. For these reasons I reject the petition [to open up silver mines in Honan].

The Hung-wu 洪武 *Emperor of the Ming*[1]

(1) Early Involvement of the State in Mining

Some involvement of Chinese political authorities in mining may well date from at least the Shang dynasty in the second half of the –1st millennium. Given the number and crucial importance of bronze weapons and ritual vessels produced in state foundries, together with its economic system relying very heavily on forced labour,[2] it would have been uncharacteristic of the Shang government not to make use of at least some force to ensure production and delivery of the requisite materials for this key industry. Unfortunately, as noted above ((*k*)(1)), the surviving evidence does not allow us to say anything precise about these early activities.[3]

Evidence of a state rôle in mining improves little for the Chou period. It is only in the *Kuan Tzu*, and therefore very late in the Warring States period (perhaps c. –300) at best, that we get the first serious discussion of the government's rôle in regard to a mineral, in this case, iron. The general policy advocated is that the government treat mountains with ore deposits as sacred places where entry by the public should be restricted. On the other hand, the *KT* also seems explicitly to reject direct operation of the mines by the government.[4] The focus, as in much of later policy-making, is on fiscal policies and their use to encourage production, as for example by setting an artificially high price for iron.

At times, however, ambitious governments or emperors were willing to engage in more direct control over production itself. The first fairly clear example of this seems to be the establishment of an iron (and salt) monopoly by the Han court in –117.[5] In this case, the government established 48 iron offices (*thieh kuan* 鐵官) across

[1] Collins (1922), p. 26. This is more of a paraphrase than a literal translation, for which see Eberstein (1974), pp. 66–7.

[2] Keightley (1969), *passim*.

[3] One would like to know, for example, whether the desire of the state to increase its supplies of copper and tin had any link with the emergence of bureaucratic forms of government able to promote mining production, as was the case with the German-speaking states of the late medieval and early modern period in Europe; Suhling (1977), p. 576, fn. 27.

[4] Than Po-fu *et al.* (1954), pp. 310–15.

[5] See Section (*e*)(2) above.

the country,[6] some with a labour force of hundreds of workers or more. Many of these 'offices' must have included foundries and mines; otherwise, there could hardly be a need for so many workers.[7] Since many of the labourers were convicts, and since some of the administration was entrusted to men who had been successful in the iron industry (i.e., without a background as officials),[8] it seems reasonably certain that the government was taking an active rôle in administering the production of iron and iron tools.

For the rest of the imperial period, government mining policies would fluctuate between more and less direct involvement by the government. This would be true even in the period from the mid-Thang (late +8th century) onward when there was a clear long-term trend for the government generally to back away from attempts to manage directly not only commerce but also productive activities such as mining.[9] After the sorry experience with state control over mining during the Ming, the Chhing State showed considerable, if not unfailing, willingness to accept private operation of mines.[10] The Yunnan copper mines, so essential to the currency system, were something of an exception though even here the long-term trend was for greater private operation.[11] Generally, however, the State increasingly limited its rôle to exercising general administrative supervision, collecting of revenues and attempting to maintain law and order in the mining regions.[12]

(2) Official Ambivalence toward Mining

Just as mining has tended to be a conservative technology, changing slowly when it changed at all, so a relatively limited number of perspectives tended to characterise official attitudes toward mining over the two millennia of imperial rule. In contrast to mining technology, however, government policies changed frequently and often dramatically, depending usually on the perspective of those officials who dominated court politics at any given time.[13]

[6] Swann (1974), pp. 271–2; 275–7; Watson (1993), Vol. 2, p. 89.

[7] It is only by such reasoning that we can even connect mining with the iron monopoly. Nothing in the surviving sources on this episode deals with mining explicitly.

[8] Chhü Thung-tsu (1972), pp. 119, 352. [9] McNeill (1982), Chap. 1; Feuerwerker (1982), p. 152.

[10] At the very beginning of the dynasty, the state adopted policies very hostile to mining in general, but these were mainly part of an effort to restore the devastated agricultural sector in north China; Pheng Yü-hsin (*1984*), p. 78; Hu Chung-kuei (*1988*), pp. 20–1.

[11] Lee (1987), Chap. 7; Vogel & Theisen-Vogel (1991), esp. p. 54. General administrative supervision might, however, go as far as dictating which areas would be supplied by which coal mines, as was the case in Shansi in the second half of the 19th century; von Richthofen (1875), p. 17.

[12] Eberstein (1974); Vogel & Theisen-Vogel (1991), p. 25.

[13] When forceful emperors were on the throne, it was their attitudes that were most decisive. For example, the Khang-hsi 康熙 emperor in +1707 rejected proposed mining tax increases in Yunnan because the court was already collecting sufficient amounts to cover the military rations to which these funds were applied and because he personally felt the increase would impose an excessive burden on the miners; Vogel (1987a), V.1. His son and successor, the Yung-cheng 雍正 emperor, was strongly opposed to mining, feeling that it was his obligation to promote agriculture and that mining had exactly the opposite effect. Satoi (*1972*), pp. 26–7. His grandson, the Chhien-lung 乾隆 emperor, often had little patience with geomantic or public order arguments proposed by those who would limit mining. Sun (1981), pp. 121–2.

The scope for policy shifts was all the greater since government policy was not restricted by a well-established body of mining law, as was the case in late medieval and early modern Europe.[14] As E-tu Zen Sun sums up the situation: 'Government policy . . . reflected a body of principles that served as guidelines for coping with each individual situation as it arose.'[15] It needs only to be added that those principles were often contradictory one with another.

The resulting policy fluctuations reflected in part a deep ambivalence that characterised much of official thinking in regard to mining. That ambivalence sprang not only from the variety of mining activities but also from very different assessments, from the government's point of view, of the importance of different kinds of mining.

There was much about most mining enterprise that caused uneasiness even among officials who were willing to accept mining as a legitimate occupation and perhaps even to lend it some kind of government support.[16] Some of that uneasiness arose from political rather than economic considerations. Mining often appeared as a potential threat to the kind of control over the populace at which Chinese governments always aimed or, to phrase it more favourably, the kind of order that was

[14] Mining law in China, both formal and customary, is a subject much in need of further study. The effort of V. K. Ting (1917) to summarise mining legislation in traditional times suffers from over-generalisation and some inconsistencies. We can certainly say, however, that the lack of a firmly rooted and well-elaborated body of law protecting rights of miners and mining communities *vis-à-vis* the government added to the instability and unpredictability of mining. We have here a dramatic contrast with Europe where an important element of mining law was the granting of a high degree of formal autonomy to mining communities, similar to the autonomy granted to cities and towns; Nef (1952), pp. 448 and 454. Nothing of this sort, or indeed any recognition of miners as a permanent, distinctive social category, was to be found in China; Vogel & Theisen-Vogel (1991), p. 53. On the other hand, the lack of a specific body of formal mining law does not seem to have been a serious impediment in day-to-day mining. Many activities such as the leasing of mining concessions tended to be handled on the pattern of practices in the agricultural sector. Above all, at least since the Sung (+960 to +1279), the Chinese economy benefited from an effective system of informal or customary contract law where contracts were to a large extent self-enforcing in an atmosphere of general trustworthiness (Jenner (1992), pp. 139–41; Naquin & Rawski (1987), p. 102) though the magistrate's court could be counted on to enforce customary practices when disputes could not be otherwise resolved (Zelin (1988), p. 116). Contracts were usually relatively simple and straightforward but they could also contain necessary provisions to meet the special needs of an activity such as mining. Thus we see, for example, mining leases that remained in force until a mine had been exhausted (often qualified by the condition that the mine be kept in continuous production). Zelin (1988), pp. 84–5. The general principle that disputes be settled wherever possible by local communities without interference from the officials, together with the location of many mining operations in out-of-the-way areas where the power of the officials was limited, meant that many if not most mining communities in practice enjoyed a considerable degree of autonomy that enabled them to organise mining operations pretty much as they saw fit. Indeed, sometimes there was no need for organisation at all. As von Richthofen, commenting in the 1870s on the mining of the extraordinarily rich coal deposits of Tse-chou 澤州 in Shansi, noted: 'Coal mines are of so little value, that legal conceptions, such as right, title and property, do not apply underground. Whoever wants to mine can do so. He makes a tunnel or sinks a shaft, at any place which is not occupied already by a mine, and extracts as much anthracite as he can profitably sell from this extraordinary coalbed of thirty feet in thickness.'

For a more extensive comparison of mining law in Europe and in China, with references to important recent studies on medieval and early modern European mining law, see Vogel & Theisen-Vogel (1991), pp. 34–8. For Greek and Roman mining law, a good starting point is Healy (1978), chap. 5. See also the very suggestive discussion of mining law from earliest times (mainly in Europe) in Hoover & Hoover (1912), pp. 82–6.

[15] Sun (1981), p. 119. The arbitrary changes in government policy that could occur at any time were mirrored in the fluidity and uncertainty that often marked the power alignments in out-of-the-way mining communities like Ko-chiu and further added to the risks of mining; Shih Kuo-heng (1947), p. 59.

[16] For one concise summary of the kinds of problems that plagued Chinese mining and caused concern to dedicated officials, cf. the +1597 memorial of Yao Ssu-jen; *HWHTK*, ch. 23, p. 3003a, translated in Eberstein (1974), pp. 96–7.

universally seen as a prime responsibility of the government.[17] Mining operations, particularly those on any scale, tended to be located in out-of-the-way and border areas over which the officials typically exercised tenuous control in the best of times.[18] Often, tasks such as lending funds to the miners or the collection of taxes had to be farmed out to what were usually referred to as 'merchants' (*shang* 商) but who must have constituted a group with widely diverse backgrounds. In any case, they often worked as much or more for their own enrichment as for the interests of the government.[19]

Then there was the problem of maintaining at least a modicum of order in the mining districts. Even with the superior military force at the government's disposal, bands of miners, enjoying a high degree of mobility, could be exceedingly difficult to deal with when they took up arms against the authorities or against the local populace.[20] In this, they were not unlike guerrilla forces in our own century.

The general character of the miners themselves also came into play. The anthropologist Thomas Greaves and his collaborators have eloquently summarised this character. Though they base their comments on the observation of modern miners, much of what they say applies with little modification to miners in earlier times, including those in China:

> Miners the world over have been noted for their solidarity, their readiness to assert and defend their collective interests. . . . One can, with reasonable security, suggest that miners everywhere are prone to a strident and stormy character. In our literature such aggressive labour unity has often been attributed to the work environment, which isolates teams of men who must depend on each other for their very survival, while counterposing them to a management that appears (and often is) unmoved by the brutalising nature of the toil and omnipresent mortal danger.[21]

In China, 'professional' miners often came from the roughest and rowdiest elements of the society. Many owned no land and thus lacked even the minimal status conveyed by landownership. Their mobility attenuated their ties to any locality.[22]

[17] As in late medieval Europe, part of the *regale* (the right of political authorities 'to dispose of mines under private lands subject to their authority') was the obligation to set up an imperial administration for regulating labour and community life of the miners; Nef (1952), p. 442.

[18] Especially in the southwest, opposition by non-Han peoples meant that Chinese miners could not carry on their activities without military protection by the government; see, e.g., Hosie (1922), p. 160.

[19] Cf. Satoi (*1972*), pp. 54–61 for a good discussion of this group in the Chhing, especially in Hunan.

[20] Eberstein (1974), pp. 74, 152–4, 157. For an example of a proposal that explicitly allowed for mining where the government could maintain some control over it but advocated 'as a precaution' the prohibition of mining in out-of-the-way 'border territories where the I [minority] people congregate', see the memorial of +1737 by the Provincial Military Commander of Kweichow; Anon. (*1983*), Vol. 1, pp. 60–1.

[21] Greaves *et al.* (1985), p. 171. Interestingly, among the circumstances that affected the degree of punishment meted out to miners who violated government prohibitions against private mining in the Ming was the size of the group involved. Miners from those groups of over 30 were punished more severely; Eberstein (1974), p. 157.

[22] Eberstein (1974), p. 154; Sun (1967), p. 46. As Su Tung-pho in the +11th century described the workers at the 36 large-scale mining and smelting complexes (over 100 workers each) at Li-kuo 利國 chien, they were 'destitute drifters, strong and fierce' (*chi han wang ming chhiang-li chih-jen* 飢寒亡命彊力鷙忍). Ever objective, however, Su also admitted that some of them were 'able and reliable' (*yu tshai-li erh chung-chin* 有材力而忠謹); *Su Tung-pho Chi, hsu chi*, ch. 11, Vol. 13, pp. 51–2.

At the same time, their living conditions and the dangers of their work placed a high premium on cooperation in order to survive.[23] Such people, especially when they congregated in large numbers, could threaten public order at any moment but were seen as especially likely to cause problems when mines gave out, leaving them without work, or in bad years when there was insufficient food.[24] Some officials, such as the famous Hai Jui 海瑞 of the Ming or the governor-general in +1735 at Canton, O-mi-ta 鄂彌達, attempted, probably without much success, to maintain a clear distinction between more easily controllable local people and more troublesome 'vagabonds' working at the mines.[25] Others, such as Lin Tse-hsu 林則徐 of Opium War fame, argued that the whole idea of the great difficulty of dispersing miners at a mine that had given out was nothing but a canard perpetrated by those who knew nothing of the real situation at mines.[26] Still, the government did sometimes find itself faced with bands of marauding miners that could number in the thousands.[27] Ray Huang would even argue that the major rebellion by the mining entrepreneur, Yeh Tsung-liu 葉宗留, which took the government five years from +1444 to +1449 to suppress, left so strong a fear among the officials that it 'proved a constant hindrance to the government's efforts at silver mining in the sixteenth century.'[28] In the right (or wrong!) circumstances, especially where good prospects of plunder (another way of striking it rich) presented themselves, miners could also be enticed into becoming mercenaries, lending their support even to uprisings that had nothing to do with mining conditions *per se*.[29]

Even at peaceable working mines, security could become an important concern of the officials. Prosperous but out-of-the-way mining operations served as an attractive target for bandits.[30] In extreme cases, the bandits might even take over an entire area of mining operations and thus deprive the government of all control over the mines as well as the revenues they produced. By the Ming period at least, it had become common practice for the government to station troops to protect mines in which it had a special interest.[31]

[23] Eberstein (1974), pp. 200–1.

[24] Miners sometimes caused another problem when, in a period of rising grain prices caused by bad harvests, they were able to pay the higher prices and thus siphon grain away from the more settled areas where the people relied on agriculture for a living; Anon. (*1983*), Vol. 1, pp. 60–1.

[25] Cartier (1973), pp. 149–50; Sun (1967), p. 48; Eberstein (1974), pp. 158–9.

[26] Sun (1967), pp. 48–9. Perhaps also in the canard class were the frequent statements by officials that gold and silver (and thus their mining) were of no use to farmers or to the people in general; Huang Yü-heng & Ai Ta-chheng (*1989*), p. 64.

[27] Eberstein (1974), p. 151; Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 1, p. 198. The miners were relatively easy to organise in part because, like the 'patricians' in the urban disorders during the late Ming in Chiang-nan 江南, they tended to share a narrow set of well-defined interests; cf. von Glahn (1991).

[28] Huang (1974), p. 242. For a good discussion of the Yeh uprising, cf. Eberstein (1974), pp. 148–50.

[29] Eberstein (1974), p. 153. The populace of an area might look on miners' bands quite differently, even helping them on their arrival to get settled, in the hope that the opening of a mine would offer side employment for the natives of the district; Eberstein (1974), p. 146. Also, the argument could be and was made that, given the fact that so many of the miners were rough types with no other (legal) means of livelihood, allowing them to work as miners could lead them eventually to abandon their bad ways; Anon. (*1983*), p. 74.

[30] Eberstein (1974), p. 96.

[31] Eberstein (1974), pp. 97, 153ff., 201. The troops of course could also come in handy for controlling the miners; Huang (1974), p. 241.

Apart from security, few officials, whatever their perspective on mining in general, would deny the ultimate responsibility of the government for maintaining at least a modicum of peace and order at existing mining sites. Hence local officials might be drawn into disputes over mining claims where rules well established for agriculture often provided little help even for surface workings and much less for underground mines. The surviving sources, however, do not provide enough information to enable us to generalise about the circumstances in which officials might be expected to intervene. At least by later times, we can assume that the miners themselves had already worked out most of the principles or rules necessary for solving most commonly occurring disputes.[32] The miners were in most cases far more likely to have the understanding of mining operations that would lead to workable rules, in contrast to government officials who only very rarely knew or cared about how mining was actually carried on.[33]

The physiocratic orientation of all Chinese governments, with its unswerving emphasis on agriculture as the basis of a sound economy, also led many officials to fear mining as a possible drain on labour power that could more productively be expended on the all-important activities of cultivation and harvest. Agriculture might also be hurt if mining led to the poisoning of waters needed for irrigation.[34] The congregating of large numbers of miners who produced no food also in general tended to drive up food prices not only for themselves but also for natives of the district.[35] A memorial by Grand Secretary Yang Ying-chü in +1765 attributes part of the problem to clever but less-than-honest entrepreneurial types:[36]

As more mines are opened in Yunnan province, so have larger numbers of miners congregated, at some places reaching hundreds of thousands of persons. This has led to an expanded consumption of rice and an over-demand for its transport, which in turn have caused a rise in food prices at the mining sites. Furthermore, there are some worthless fellows who, alleging that they have discovered copper in a certain mountain, present their claims, collect a group of like characters and begin to test-mine. They begin by approaching households that possess [surplus] rice and borrow food from them, calling this 'rice portions.' The amount of rice portions donated in this way will be used in future to determine the proportion of the mining profits to be paid to the donor. When after a few years it is seen that the mine yields

[32] We have given above (Section (*h*)(3)) an example of such a rule: when two miners approaching from different directions saw each other's light, they were to break off and start working in another direction. Von Richthofen provides another example. In the late 19th century, at the gold placers along the Han River in Hupeh, the miners (who practised farming during much of the year) came together at the beginning of the mining season each year to subdivide and stake off working areas, each of which was assigned to a particular miner; von Richthofen (1874), p. 4.

[33] Even when officials made on-site inspections of the mines, their primary concern with maintaining order meant that they were much more likely to check that the registers providing details on the miners employed were well maintained than to concern themselves with actual mining techniques. It was this information that they regularly required in reports from the operators of mines; Lü Tai-ming (*1986*), p. 161. It was also mainly from checking the records of the number of miners actually at work that they tried to keep up with actual production activity at the mines and smelters; *SHY:SH*, ch. 34, p. 24 a–b. This should be kept in mind when reading Vogel's contentions (1987a, V, 2) that officials charged with mining responsibilities in +18th century Yunnan took a significantly greater interest even in technological matters than their predecessors in the Ming and even in the early Chhing.

[34] Vogel & Theisen-Vogel (1991), p. 26.

[35] Eberstein (1974), pp. 154–5; Vogel & Theisen-Vogel (1991), p. 26; Li Hua (*1990*), p. 52.

[36] *Yun-nan Thung Chih*, ch. 74, p. 22; Sun (1964), pp. 59–60.

nothing, they will move to another locality, and again borrow rice from the householders. In the end the mines remain an empty plot while the food is simply wasted.[37]

One wonders what proportion of these 'worthless fellows' were really dishonest, as implied, and what proportion were simply themselves victims of deposits that did not pan out.

A real concern not to violate geomantic (*feng shui* 風水) prescriptions also made some officials wary of mining, though there is no lack of evidence that such concerns sometimes served as a subterfuge to mask less noble motives, one that could be very effective precisely because widespread acceptance of these ideas made them difficult to refute.[38] In the Ming and Chhing, probably the greatest geomantic impediments to mining were to be found in the Peking region where coal mining was often prohibited because of possible disruption of the geomantic forces affecting the imperial tombs[39] or even because at least some of the emperors themselves were believers in geomancy.[40] For the situation elsewhere, at least in the late Chhing, the comments of Baron von Richthofen, who travelled extensively if rather rapidly through many parts of the empire, are perhaps only slightly too cynical: 'The mandarins are well aware that, though those who pay for mining enterprises may fail, they, themselves can only gain. In all the mining districts which I have visited, they have acted in accordance with this principle, and I never met with any instance where the Feng-shui superstition did interfere with extraction of minerals, provided it could be done with profit.'[41]

Those officials who took seriously their responsibility to promote good morals among the people looked askance at the spirit of greed that mining often seemed to encourage. If we are to believe the *Huai Nan Tzu* 淮南子 when it tells us that the sage 'Shen hid gold deep in inaccessible mountains in order to prevent a spirit of greed among the people',[42] such thinking dates back to the dawn of Chinese history.

Finally, mining was a notorious target of fiscal exploitation by local officials or other agents of the government.[43] One of the most prevalent practices, found in virtually all periods, required miners, after paying a fixed percentage of their production as

[37] For background on these problems, in particular the Burma war which caused shortages of both rice and transport facilities, cf. Vogel (1987a), V.1.

[38] Von Richthofen notes that, like most other things in China, sincerity and depth of belief in geomancy varied greatly in different regions of the empire; von Richthofen (1872), p. 1. For belief on the part of the élite in geomancy, see Freedman (1979), pp. 315–17.

[39] Wang Chung-lo (*1956*), p. 27; Lü Tai-ming (*1986*), pp. 154ff.

[40] In the area of Fu-shun 撫順, the major coal producting region of Liaoning province, there was still in the late 1950s a widespread tradition that the early Chhing emperors had forbidden coal mining on a particular seam because the seam was interpreted to be a 'black dragon' (*hei-lung* 黑龍) that had come upriver to enter the earth at Fu-shun; Hung Yü & Wan Chiang (*1958–1959*), October 31, (1958), p. 5. On the other hand, as E-tu Zen Sun has noted, the Chhien-lung 乾隆 emperor most emphatically did not share those beliefs: in +1787, when he heard that officials were using geomantic arguments to prevent the opening of a sulphur mine near Peking, he rejected those arguments as 'fantastic' and 'preposterous'; Sun (1968), p. 832 (also Sun (1981), p. 121).

[41] Von Richthofen (1871), p. 16. It must of course be kept in mind that evidence from the unsettled second half of the 19th century can only with great care be drawn on to support generalisations about earlier periods of China's imperial history.

[42] Ma Yun-kho (*1932*), p. 9.

[43] Williamson (1867), p. 67; Gray (1878), p. 357; Anon. (1861); Golas (1989), p. 420. In the late 1930s, one of the informal titles of the provincial governor of Yunnan, given to him by businessmen in the tin industry at Ko-chiu, was 'head of the local bandits'; Shih Kuo-heng (1947), p. 55.

a tax, to sell most if not all of their remaining production to the government. Often, the prices were set so low that they precluded any profit or even the covering of expenses. In borderline cases, the result might mean that the miners could work only very high-grade ores. This was the case, for example, in Tung-chhuan 東川 in Yunnan in the 1890s when only ore that contained 10 per cent or more copper was economically exploitable.[44] Many mines that might otherwise be viable were thus forced to close.[45] This must have had at least some negative effect on the development of mining technology insofar as it made economically unviable deep workings where the greater challenges, in the right circumstances, could spur on inventions and innovation.[46]

In a period like the late Ming, the difficulties for the miners could be further exacerbated by more direct interference from the capital than was usually the norm. In the reign of the Wan-li 萬曆 emperor (+1573 to +1619), a central government strapped for funds relied heavily on eunuch mining inspectors who were sent out from the capital to the mining districts. Though their commission was to increase the central government's take from mining, they became notorious for devising creative ways of siphoning off mining revenues for themselves.[47]

Even without any particularly evil intent, local officials often found themselves forced to press miners hard for revenues. They frequently had to contend with inflexible revenue quotas imposed on them by the central government, quotas that failed to take into account the inevitable fluctuations in mining production that were well beyond the control of the miners and mining entrepreneurs.[48] Where the officials, not content with simply taxing production, actually took over direct control of mines and miners, their efforts to make the mines pay often led to brutal treatment of the miners, driving many of them to abscond or, where that was not possible, to commit suicide.[49] Thus many officials as well as some emperors (see

[44] Ting, (1915), p. 210.

[45] A letter by a Chhing official, Li Fu 李紱, commenting on copper mining in Yunnan, describes the problem very accurately: 'The fixed copper price paid by the government is not sufficient to meet . . . expenditures. That is the reason why mine owners often report that their mines are old and deposits are depleted. This is merely an excuse to escape; actually the mines are not old, nor are the deposits depleted.' Pheng Tse-i (*1957*), p. 345; translated in Sun (1964), pp. 71–2. Another tactic used by local officials was to require miners to buy their tools from the government, at inflated prices; Eberstein (1974), p. 73. For uprisings of Yunnan miners against official exactions, cf. Chhen Lü-fan *et al.* (*1980*), pp. 24–8.

[46] Circumstances such as those that prevailed in central Europe during the Renaissance, and to which the writings of Agricola, among others, give abundant testimony. Interestingly, the inability to solve these problems was one of the reasons, along with the decimation of the population by the plague of the mid-+14th century and the devastation of the Hussite Wars in the first half of the +15th century, for the century of depression in the central European mining industry from about +1350 to +1450 that immediately preceded the great boom that began in the late +15th century; Long (1991), pp. 323–4.

[47] For example, one technique was to levy 'protection' fees on landowners who wished to avoid having their property explored for ore deposits; Peterson (1979), p. 73; Eberstein (1974), pp. 82ff. and *passim*.

[48] Golas (1989), pp. 415–17; Huang (1974), p. 241; Cartier (1973), pp. 149–50; Vogel (1987a), V.1. A creative answer (or at least partial answer) to the problem of meeting steady quotas despite fluctuating production emerged in the +18th century with the designation of new mines as 'branch mines' (*tzu-chhan* 子場) belonging to a 'parent mine' (*mu-chhang* 母場). Administratively, the two were handled together. Vogel thinks that the branch mines were originally taxed but that the taxes later ceased so that production from the branch mines could make good quota shortfalls of the parent mine; Vogel (1987a), V.1.

[49] Sun (1967), p. 56; Eberstein (1974), pp. 96–7.

the words of the Hung-wu emperor at the head of this section) came to the conclusion that the only effective way of preventing the abuse of miners that was so often the norm in both private and government mines was to prohibit mining wherever possible.

On the other hand, the potential benefits of mining, not only for the government but also for the miners and for the people at large, assured that it would not lack for vigorous defenders in officialdom. As Mark Elvin has noted, government attitudes 'were generally benign toward anything that had a positive effect on the people's welfare.'[50] One of the major concerns of local officials in China was that there be work available for the people under their jurisdiction.[51] Mining was therefore often advocated because it provided supplementary income for farmers in the off-season or, an even more persuasive argument, provided work for those who had no other means of support.[52] The government also recognised that mining could provide work relief for populations that had met with natural or man-made disasters.[53] Indeed, the government effectively had its own definition of 'small-scale' private mining toward which the officials ordinarily were quite tolerant.[54] As long as mining was carried on mainly by natives of a locality, either farmers on a part-time basis or landless natives on a full-time basis, and did not reach a scale where it drew people, including professional miners, from other localities, officials were usually tolerant of it even when technically it was illegal.[55] Of course, such policies, insofar as they could be implemented,[56] stood directly in the way of one of the most potent forces for raising the level of mining technology: the free circulation of miners with considerable experience and expertise.

[50] Elvin (1975), p. 110. If such considerations dovetailed with the government fiscal interests, for example the increasing revenue it drew from coal taxes in the Ming and Chhing (Lü Tai-ming (*1986*), pp. 146ff.), so much the better.

[51] King (1965), pp. 234–5.

[52] Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, p. 600; Sun (1967), p. 52; Vogel (1989), p. 155. Eberstein argues, however, that in the Ming period at least, the idea of using mining to provide work for those without land who spent most of their time wandering in search of work was exceptional in the thinking of the officials, being usually a reaction to the threat of uprisings by these homeless unemployed. The more common goal of the officials was to reintegrate these rootless people into the sedentary farming population; Eberstein (1974), pp. 159–62. Surely, though, local circumstances must have done much to condition the attitudes of specific officials. In particular, there were cases where such reintegration was simply not in the realm of possibility; for some examples, see Sun (1967), p. 52.

[53] Sun (1967), p. 53, fn. 18; Eberstein (1974), p. 100. Recognition that mining was 'socially useful', that it could provide work for people who otherwise had no means to support themselves, was an important component in the thinking that led to the major change toward a policy of general encouragement of mining in the Chhien-lung 乾隆 period (+1736 to +1795) of the Chhing; Vogel & Theisen-Vogel (1991), p. 33; Lü Tai-ming (*1986*), pp. 111–16.

[54] Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 1, p. 198.

[55] Eberstein (1974), pp. 158–9; Lü Tai-ming (*1986*), p. 129. It should be noted that the difficulty of tracking down such small mines would by itself often have frustrated official efforts to close them. We have noted above ((*k*)(5)) that, in the great tin-mining centre of Ko-chiu, there were still in the 1930s some 1,000 privately owned mines spread out over about 1,150 sq. km of mountainous land. Any supposed advantages from across-the-board attempts to close such mining clusters would hardly have appeared to most officials as 'cost-effective'. Hence, a high proportion of mining in traditional China was illicit, with greater or lesser attempts by the miners to conceal their efforts from the officials, as when gold washing (Anon. (1898), p. 130), coal mining (Lü Tai-ming (*1986*), pp. 159–60), and undoubtedly other forms of mining were carried on only at night.

[56] And they often could not be, as in Yunnan during the Chhing; Vogel (1987a), V.2.

Smaller mines also mitigated the wasting side of the industry: deposits would last that much longer the less intensively they were exploited.[57] But when mining outgrew these limits, the government was likely to react, in some cases even by sending troops to forcibly close the mines.[58]

The inexorable needs of the government for the products of mining of course powerfully conditioned official attitudes. In certain periods and with certain metals such as copper, iron, lead, tin and zinc, the government's main concern was to get enough of these metals to meet its huge currency and weaponry needs.[59] In these cases, theoretical objections to mining were unlikely to carry much weight. Then there were the major and indispensible revenues mining provided for the government. Time and again, policies that prohibited mining were reversed not because of any confidence that the abuses that had given rise to the policies in the first place could be avoided but simply because the government felt it needed the revenue.[60] At the very end of the Ming, as we have seen above ((*c*)(5)), the court even ordered the translation of Agricola's *De Re Metallica* into Chinese mainly in the hope that use of the Western mining and smelting methods it described would raise mining production in China and thus provide a new source of revenue for the government's depleted treasury.

Though all of these considerations led to considerable support for mining among officials, they left open the more specific question of precisely how the officials should deal with mining that had been authorised. Time and again, the debate centred on how much direct control the government should exercise over mines and miners. Should the officials run the mines themselves; or should they leave the mines in private hands and simply tax the output; should they combine a tax with forced purchase of all or most of the output?[61] Except for certain exceptions in cases of major mining operations that were crucial to meet government needs (such as copper for coinage), the arguments of those who advocated that the government limit its efforts to taxing the mines or to a combination of taxation and forced purchase tended to prevail.[62] There was much in Confucian orthodoxy that argued that the state should 'care for the people by exercising the least interference in the people's economic pursuits'.[63] It was also argued that natural resources ('the benefits of the mountains

[57] This was the basis for one objection to the introduction of foreign mining methods into 19th century China; Anon. (1892), p. 98. Not surprisingly, the foreigners often failed to perceive the reasonableness of the government's case.

[58] Eberstein (1974), pp. 158–9; Sun (1967), pp. 52–3.

[59] It has been argued that this led the government to stress maximising production rather than maximising its control; cf. Hua Shan (*1982*), p. 123.

[60] One wonders how much more supportive of mining the Chinese government would have been had it been as dependent on mining revenues as +15th and +16th century Saxony where regalian dues on silver mines accounted for one-quarter of total revenues in +1473, and two-thirds in +1530! Braunstein (1983), p. 582.

[61] This later practice is the equivalent of the 'right of preemption' in European mining law; Nef (1952), p. 447.

[62] The large and constant need for copper at the government mints certainly goes far to explain why the Chinese governments, especially in the later imperial period, were far more likely to become actively involved in copper mining than in other kinds of less critical mining operations; Vogel & Theisen-Vogel (1991), p. 54.

[63] Chhen Chih-jang (1980), p. 3.

and marshes' *shan tse chih li* 山澤之利) should belong to the people at large and not be confiscated by the government for its purposes. Sometimes, this principle was supplemented with what purported to be the lessons of experience, as in Chhiu Chün's *Ta Hsueh Yen I Pu* 大學衍義補 (Restoration and Extension of the Ideas of the Great Learning): 'If the officials take the benefits of the mountains and marshes, these will be insufficient. If the people take them, there will be a surplus.'[64] In other words, private mines would have a more successful track record than mines run by the government. Some officials agreed, contending that the government could save itself many problems and derive greater revenue from mines by allowing them to be privately run and publicly taxed, rather then by trying to run the mines itself. A typical expression of this point of view occurs in a +1682 memorial by Tshai Yü-jung 蔡毓榮:

> Your foolish servant considers that the earth does not give up its riches without the labour of man. If officials are ordered to open up mines, the expenses turn out to be higher than estimated. In this period of ceaseless military expenditures, where will the money be found? Moreover, once excavations have begun, veins sometimes prove to be thin and erratic, so that halfway through the investment comes to naught. In other cases, the deposit is rich and dependable but its out-of-the-way location makes it difficult to get information on what is going on so that the way is open to peculation by the officials and the people alike. In this case, how much profit will accrue to the State? There is no policy more expedient than to allow the people to open up mines and have the officials collect taxes on them.[65]

On the other hand, Confucian-sanctioned concern for the people's welfare meant that Chinese governments often felt obliged to look after the welfare of miners, whether at government or private mines. Thus officials might limit the depth of mines since, often enough, greater depth meant more accidents that led to the injury or death of miners.[66] Or they might order better timbering, especially in coal mines.[67] They surely would feel obliged to do something when they learned about the dreadful conditions in which miners were sometimes forced to work.[68]

Finally, no government started with a clean slate when it came to setting or changing mining policies. In particular, any efforts to establish or extend direct government control over existing mining operations would have to contend with vested interests. There was little reason to believe that the people profiting from the exploitation of private mines would meekly accept the effective confiscation of their

[64] Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 1, p. 191.

[65] *Huang Chhao Ching Shih Wen Pien*, ch. 26, cited in Chhen Lü-fan *et al.* (*1980*), p. 34. See also Wu Chheng-ming & Hsu Ti-hsin (*1987*), Vol. 2, pp. 599–600. This is a good example of the *laissez-faire* policies in regard to direct management that tended to characterise the Chhing dynasty (+1644 to 1911); Feuerwerker (1982), p. 152.

[66] Lü Tai-ming (*1986*), p. 197. [67] *Ibid.*, p. 199.

[68] Ebrey (1981), pp. 233–4; Sun (1967), pp. 56, 64; Sun (1981), pp. 106, 114–15. For similar problems in the saltworks of Szechwan, see Vogel (1990), pp. 200–2. His conclusion for the saltworks seems to hold generally true for mining: although the government officials were sometimes slow to react to brutal conditions of forced labour, they usually did react eventually and their actions or the threat of actions was enough to ensure that forced labour was the exception rather than the norm. For a less sanguine view, cf. Lü Tai-ming (*1986*), pp. 221–4.

livelihood by the government. Especially in those many remote mining areas where the power the government could bring to bear was limited at best, their resistance might well prevail.[69]

(3) The State Impact on Mining Technology

With our present knowledge, we are still far from being able to determine with much confidence the overall impact of State actions on mining technology. This question is related to, but not synonymous, with how one assesses the effect of State actions on the mining industry in general. That assessment in turn is part of a larger assessment of the effects of government actions on the overall economy. These are subjects on which competent scholars have often reached quite different conclusions.[70] For the Ming and Chhing periods, for example, we have Albert Feuerwerker's contention that 'Neither the direct nor the indirect influences of the state on the economy were major factors determining the nature and rate of ... [late imperial] premodern economic growth'[71] while James Lee would claim that 'the Chinese state was the largest and most powerful economic institution in late imperial China' and that the 'power of the public sector to determine the behaviour of the private sector was great'.[72] Further studies will undoubtedly lead to an increasingly nuanced understanding of the rôle of the State in the economy, one that makes high-level generalisation far more difficult but gives us a much more textured appreciation of the varying effects of different policies on different sectors of the economy in different periods. For example, it would seem difficult to deny that the constant strong government demand for copper to supply its mints exercised a clearly positive influence on the development of copper mining,[73] and Hans Ulrich Vogel has rightly stressed that the considerable government investment in transportation facilities was an important precondition for the flourishing Yunnan copper industry in the Chhing.[74]

It is somewhat easier to generalise when we focus on government policies that impacted or did not impact specifically on technology. With certain exceptions such as the copper precipitation process in the Sung[75] or occasional efforts to promote mining in a certain area by actively recruiting mining specialists from outside the area,[76] few government actions were aimed directly at mining technology. This was an area that, regardless of their opinions on mining in general, the officials

[69] Chhen Lü-fan *et al.* (*1980*), p. 33. Teng Tho has provided a striking example of how much mining could be simply beyond the government's control, or even knowledge. As late as the +18th century, in a metropolitan prefecture, the local gazetteer mentions only one state-run mine. Yet we know from other, non-official sources, that well over 100 private mines were in operation there at that time! Teng Tho (*1956*), p. 9; Cartier (1967), p. 60. It was in many cases simply beyond the capability of the officials to get anything in the way of accurate information on private mines located in out-of-the-way if not virtually inaccessible areas.

[70] Golas (1989), pp. 418–21. [71] Feuerwerker (1984), p. 322. [72] Lee (1987), p. 8.

[73] Golas (1989), p. 414; Vogel (1987a), I.2. [74] Vogel & Theisen-Vogel (*1991*), p. 29.

[75] See (*j*) above. [76] Golas (1989), p. 420.

were ordinarily content to leave outside their scope of activity.[77] For example, as the Yunnan copper mines reached greater depths in the +18th century, there seem to have been no technological advances to cope with growing problems of haulage, water control, ventilation and the like. By this point, improved technology along the lines of what one finds in Agricola's *De Re Metallica* would undoubtedly have been very expensive and could probably only have been paid for by the government. But the government did nothing.[78] Its attitude could hardly have been more different from that found, for instance, at the princely courts in Germany where 'in some cases the prince's mining advisor was among his most respected counsellors.'[79] Even when the government engaged in what was probably its most widely used policy to promote mining, that is, the lending of capital to the miners, the loans were usually in the form of working capital and seldom for infrastructure or improved technology.

On the other hand, such abstention by the officials from participation in technical matters may in some ways have been more a blessing than a hindrance. Lothar Suhling, among others, has stressed how technological innovations can be hampered when too much control is exercised by those who have high political and social status but little technical competence,[80] certainly a fair description of most Chinese officials. Moreover, the selectivity sometimes exercised by officials when granting mining concessions to private individuals, insisting that they demonstrate they had sufficient capital to develop the mines effectively, may have had a more positive if indirect effect on mining methods (and therefore mining technology in the broad sense) than direct intervention in decisions about what technology to use could be expected to have had.[81]

[77] Vogel (1987a), I.2. On the other hand, there are indications of a greater willingness among officials of the Chhing (especially those dealing with the Yunnan copper industry) to involve themselves in specifically technical activities such as prospecting or smelting; *Ibid.*, V.2; Vogel & Theisen-Vogel (1991), p. 30. To the extent that this was actually the case, it was probably due in major part to the career opportunities such expertise afforded at that time. This is a question that needs further study, not only for the Chhing but also earlier dynasties. Two studies that suggest some of the directions in which such studies might proceed are Hartwell (1971) and Smith (1991). Such studies should also address specifically what effects greater involvement by officials, insofar as it occurred, had on the actual technical operation of mines.

[78] Arnold Pacey is generally correct in suggesting that there was in China 'a tendency, basically realistic, to see the solution of practical problems in terms of good organisation and effective government. Technology was left to craft workers and entrepreneurs.' Pacey (1990), p. 93. Thus the government might lend working capital to the miners but seldom made any effort to direct the spending of that capital in technologically more advanced ways.

[79] Morrison (1992), p. 56. [80] Suhling (1978), p. 145. [81] Thang Ming-sui *et al.* (*1958*), p. 55.

(*m*) CONCLUSION

Chinese mining in the latter part of the imperial period was a very large industry that nevertheless relied overwhelmingly on small-scale, not to say primitive, techniques (see above, (*e*)(1)(ii)(δ)). It was very large both in terms of total output and the numbers of workers it engaged (see Section (*b*)). Moreover, individual mining operations, while normally quite small, sometimes employed hundreds of miners and support personnel, occasionally even thousands. Despite this scale, however, many of the tools and procedures on which the industry mainly relied even in the 19th and 20th centuries would not have surprised a miner of the Warring States period, more than two thousand years earlier.

The sluggish development and even occasional retrogression of Chinese mining technology after its quite promising advances down to the Warring States period demands at least an effort at explanation. This is especially true for the later imperial period from about the +8th century on, when Chinese governments regularly endeavoured, and not without success, to stimulate production. We can also fairly confidently assume that, during the same period, private mining entrepreneurs were not entirely immune to the lure of greater profits that might come from higher production.

Why, then, did Chinese mining technology display such limited advance after the Warring States period? Why did mining and metallurgy never play in China a vanguard rôle as was the case, for example, during the Renaissance in Europe?

We are now in a position to hazard some answers to those questions. They can perhaps best be discussed in terms of: (1) the crucial importance that understanding of ore deposits and their environments played in mining technology; (2) characteristics of the technology itself that inhibited advances beyond a certain point; (3) those social, political and economic factors that created an environment to which small-scale primitive mining was ordinarily the only viable response.

Technological capacity does not mean the same thing in mining as in many other technologies. To a degree not true for other technologies, mining was acutely dependent on what nature provided. Even agriculture, which also must respond to natural endowments such as climate and land, usually offers farmers a certain number of options. Within limits, they can choose what to grow and how to grow it. This possibility of choice could even lead to controlled experiments to determine which seeds and practices worked best on a given piece of land.[1] In certain circumstances, farmers could modify natural endowments, as by terracing mountainsides to obtain level fields for cultivation or by making use of irrigation. In the case of mining, such options were largely absent. One could not choose to mine gold, or tin, or coal, depending on which promised to be more profitable. Deposits were either there and

[1] Elvin (1975), pp. 94–5.

economically workable, or they were not. One could only mine what was there. How one mined was also largely dictated by the nature of the deposits.

Consequently, knowledge of what minerals were present or likely to be present was the best tool available to the miner in his quest to appropriate nature's largely hidden and recalcitrant resources. That meant the right kind of understanding of the natural environment. Over time, miners did learn from experience where deposits were more likely to be found (see (*f*)(4)), but the variety of mining environments and the essential unpredictability of deposits meant that they had nothing that corresponded to the kind of understanding farmers could acquire from hands-on experiments over which they maintained a degree of control. Even failures could instruct the farmer in a more consistent fashion than was true for the miner. And farmers could be fairly confident of duplicating successes by repeating the same actions. Because for the miner each environment and each mine offered its own distinctive set of challenges and opportunities ((*a*)(2)(ii)), what worked or what occurred in one place was of only very limited help in guessing what another site might offer and how to get at it. As we have stressed, an intuition that resisted codification was often the best aid for prospectors and miners ((*a*)(2)(ii)).

Beyond that, the knowledge that miners needed above all was the kind of knowledge provided in our day by sciences such as geology ((*c*)(2)). That kind of knowledge would have helped not only in finding deposits but also in providing at least hints of how to work them most effectively. How far the Chinese were from a useful body of 'geological' knowledge shows up strikingly by even a cursory examination of what +16th century European works such as Biringuccio's *Pirotechnia* or Agricola's *De Re Metallica* have to say about ores[2] compared with Sung Ying-hsing's scattered comments almost a century later in the *TKKW*.[3]

To be sure, practical experience and intuition could substitute, if only imperfectly, for some of that knowledge ((*d*)(3)). This was probably especially true for major mining areas such as the copper and tin mining in Yunnan. But it would have been an intellectual challenge of the first order to take the variety of practical knowledge available and to synthesise it into general principles that could be of use in a variety of mining environments. Moreover, the illiteracy of nearly all the miners and the lack of interest in mining on the part of those who were literate ((*c*)(2)) precluded the emergence of a tradition of writing on mining that alone might have led to codification of what had been learned and the transmission of that knowledge from generation to generation. Again, one sees a sharp contrast with agriculture, where farming calendars and handbooks were in wide circulation at least by the +11th and +12th centuries.[4] In the absence of a tradition of compiling mining knowledge in written form, overall understanding of the mining environment was doomed to glacial advance if any at all. And without that improved understanding,

[2] Smith & Gnudi (1959), esp. book one, chaps. 1–6; Hoover & Hoover (1912), esp. book III.

[3] Creating an awareness of the very possibility of such knowledge might have been the greatest contribution that could have been made by the wide circulation of a Chinese translation of Agricola's *De Re Metallica* ((*c*)(5)).

[4] Cf. Bray in Vol. 6, pt. 2, pp. 47–76; Golas (1980), p. 310.

the chances of significant progress in overall technological capacity were remote. Chinese miners would instead continue a heavy reliance on non-rational 'techniques' including offerings to spirits, carrying on mining so as not to offend the spirits and an overwhelming reliance on luck ((*k*)(4)).

Certain unique characteristics of mining technology in the narrow sense (the actual methods used to procure minerals or ores) also served as major obstacles to technological advance in premodern conditions. Important among these was the fact that options for mechanisation are narrowly limited in traditional, small-scale mines. We noted in the introduction mining's overwhelming reliance on brute force to break the rock and release the ore. In our discussion of underground mining, however, we had a great deal to say about tools ((*h*)(2)(i)), little to say about machines. This was not because the Chinese were lacking in inventiveness or mechanical knack but because it was energy and not mechanisation that was mainly needed at the rock face. Apart from brute human energy, the only other means available before modern times for breaking rock were firesetting and gunpowder.[5] Firesetting was discovered early and presumably used where practicable ((*h*)(6)) while blasting with gunpowder suffered from many limitations that prevented its widespread use in mining ((*h*)(7)). Where mechanisation could usefully come into play was especially in hoisting ((*h*)(8))[6] and control of water in the mines ((*h*)(11)). Even here, the potential for mechanisation was limited by a number of factors. More sophisticated equipment could be simply too costly to be feasible for relatively small mines.[7] Non-human energy to power larger machines, including animal power,[8] was also in scarce supply.[9] Few mining areas in China had access to funds on the scale that built, for example, the great water diversion or wood transport systems in early modern Europe.[10] Thus, workable devices that were invented or, more often, borrowed from other technologies (especially agriculture) in early times tended to continue in use without significant improvement or replacement.

The absence of mechanisation may have meant that most of traditional Chinese mining was crude in the sense that it was carried on largely by human labour using simple tools. That does not mean, however, that it was unskilled. We have seen many examples that show just the opposite, for example the sophisticated timbering already

[5] Animal, water and wind power were all difficult to apply within mines, especially at the rock face, though animals were widely used for haulage in the larger coal mines of the late imperial period; Lü Tai-ming (1986), pp. 199–200.

[6] Stewart (1930), p. 891. [7] Elvin (1973), part three, esp. chap. 71.

[8] Arthur Easton, writing in the second decade of this century, noted that each water buffalo at a Szechwan salt well required about 40 men to 'feed, water and care for them' and that the energy of humans was so much less expensive than the energy of the water buffaloes that the practice was for men to bring water to the ponds where the animals bathed rather than driving the animals to the water; Eaton (1945), p. 543.

[9] Availability of energy to power machines should be added as a consideration to Athar Hussain's hypothesis that mechanisation took place in China only when machines offered 'an overwhelming technical advantage over beasts or humans' or when the machines were very simple and cheap; Hussain (1989), p. 248.

[10] Hollister-Short (1994). And it should not be forgotten how slowly mechanical inventions spread even in the great mining operations of central Europe in the +15th and+16th centuries: at Schwatz, the leading mining centre in Tyrol, a bucket brigade still served to remove water up an inclined shaft; Nef (1952), p. 467. Danuta Molenda estimates that, between the +14th and +17th centuries, barely 10% of European mines underwent significant technological improvements; Molenda (1988), p. 69.

in use by the Warring States period ((*h*)(4)) and the ability to judge the quality of ore by means of simple washing procedures combined with keen observation (Section (*i*)).

Another unique characteristic of mining is that it very often becomes more dangerous under the conditions that encourage the use of more advanced technology, above all deeper and larger underground openings that may be more subject to collapse or flooding. The danger was all the greater in traditional workings that were marked by what one report has called a 'general lack of any providence'.[11] That is, premodern mines are typically worked on a shortsighted day-to-day basis with little or no overall planning for how the deposit can best be worked and with problems, accidents and the like dealt with only on an *ad hoc* basis with measures just sufficient to meet the immediate need ((*f*)(3)). This approach is adequate for primitive, relatively shallow mines that usually have a 'remarkably low accident rate'[12] but greatly adds to the danger in deeper, larger workings.

Among the broader conditions that influenced how mining was carried on in China right into this century, one can hardly overestimate the effect of her enormous pool of cheap labour. One of the reasons for the wave of technological improvements in central European mining from the +15th century on, including increasing reliance on animal and water power,[13] was the shortage of labour in the wake of the Black Death. Indeed, there is often 'an inverse relationship . . . between technological advance and the availability of labour . . .'[14] Chinese mining provides an especially good illustration of this principle. There, an abundant supply of human muscle-power dovetailed with a highly energy-dependent technology in which human labour was either the only or the cheapest source of energy. Moreover, to an extent that has yet to be assessed, both miners and officials probably resisted at least labour-saving forms of new technology, out of fear of unemployment and, by the latter, a concern over the possible unrest it might generate.[15] The result was that greater inputs of human labour regularly substituted for improved technology. Indeed, one would search probably in vain for another case where so much highly labour-intensive mining was carried on with so little return to the miners as in traditional China. This was so generally true that extensive mining operations could as easily indicate great poverty as any kind of prosperity.[16]

While abundant cheap labour (together with recurrent shortages of capital) served to inhibit technological improvements, especially in the unprecedented conditions of overpopulation in the late imperial period (+16th century on), it had just the opposite effect on the overall growth of the China's mining industry. Extremely low labour costs made possible the exploitation of many even quite poor deposits ((*d*)(4)) that could never have justified the costs of more advanced mining methods. Well into this century, the efforts of foreigners and Chinese to introduce modern

[11] United Nations (1972), p. 69. [12] *Ibid.* [13] Vogel (1991c), p. 90.
[14] Carneiro (1974), p. 183. [15] Vogel (1991c), p. 91.
[16] This has been well understood by many Western observers since the point was first made by von Richthofen to account for the ubiquity of gold placer mining in China ((*a*)(2)(iii)). There are other examples, such as the extensive mining of the so-called 'Red Bed' copper deposits in Yunnan and Kweichow where the poor tenor of the deposits assured only the most minimal returns from the mining; Bain (1933), p. 170.

methods into the mining of gold, silver, quicksilver, lead, tin, zinc and other minerals repeatedly foundered on the dilemma that the decrease in labour costs made possible by the new techniques was not sufficient to counterbalance interest and amortisation costs on the equipment investment.[17] Hence, the repeated comments by outsiders about the failure of the Chinese to use better (invariably more expensive) technology seem somehow to miss the point. They perhaps reflect too great an infatuation with up-to-date technology for its own sake and insufficient attention to the requirement that, like other economic activities not subsidised by the government, mining had to pay its way, had to at least break even or, preferably, make a profit.

Of course, more astute observers understood this. We have already cited ((*k*)(5)) Maxwell Steward on the need for Western mining engineers in China to recognise when hand labour would be more economical than the use of machines.[18] He might also have added that much of the technology Western engineers had sought to introduce into China was singularly inappropriate. For example, the thrust of technological improvements in 19th century British coal mining was not to increase output per worker but rather to stave off diminishing returns. China, however, had much more abundant coal resources that had not been as intensively exploited as those in Britain. It is not surprising, then, that China's native mines were often able to hold their economic ground against mines employing the new technology.[19] Many succeeded in part by operating only when 'the opportunity cost for labour was lower', that is, they were open only in the slack seasons in agriculture. Modern mines, by contrast, had to pay a premium for year-round labourers.[20]

The especially high risk that China's typically small and irregular deposits introduced into mining elicited different responses from different sectors of the industry. Peasants doing some mining on the side to supplement income from farming were not only less dependent on what they earned from mining but were also especially averse to risk.[21] They tended to see in mining the possibility of a modest revenue stream to be maintained as long as possible. This could best be accomplished by limited, small-scale exploitation in which the most primitive technology was both cheap and adequate. In larger mining operations, the desire to minimise the risk of capital expenditures that could all too easily become open-ended led entrepreneurs

[17] Read (1920), p. 298.

[18] For example, according to the calculations of Wong Lin Ken, a 16 hp steam pump with four-and-a-half times the discharge capacity of a square pallet chain pump required in the late 19th century installation costs 16 times those of the chain pump and maintenance costs about 18 times those of the chain pump! One result was that it was sometimes more economical to install a small steam engine to power a chain pump rather than install a steam pump; Wong Lin Ken (1965), p. 57.

[19] Wright (1984), pp. 34–5. There is evidence to suggest that, even in terms of output per coalminer, there was sometimes no great difference between modern and native mines. Of course, the quality of the output has to be considered (e.g. slack vs. lump coal) and, though we have no quantifiable information, there is some evidence to suggest that the product of native mines was poorer. On the other hand, poorer coal was probably satisfactory for most of the Chinese uses so that the higher costs of the modern mines could not be offset by sufficiently higher market prices for their superior product.

[20] Wright (1984), pp. 33–5. Presumably, labourers were willing to work for less at native mines because of certain non-monetary forms of compensation such as less dangerous and unhealthy working conditions and a more relaxed work discipline; cf. Brown & Wright (1981), pp. 69–70; Chesneaux (1968), p. 87.

[21] Scott (1976); Godoy (1990), pp. 9–18.

to (1) minimise as far as possible their capital investment in mines; (2) dribble out their capital funds only as needed and conditioned on their subjective estimation of the progress being made; (3) leave their capital at risk for the shortest possible period by insisting on rapid returns; (4) demand a fixed return regardless of how the mine was doing; or (5) some combination of these strategies. All of these actions tended to choke off capital available for investment in mining, including investment in better technology ((*k*)(5)).[22]

China's irregular deposits with their small-scale workings did not simply increase the risk of mining in a general way, however. In many cases, such as the Ko-chiu tin mines in southern Yunnan, they precluded the kinds of organisation and management that might have opened the way to a higher degree of mechanisation and, instead, encouraged highly fragmented exploitation that put a premium on cheap labour instead of more and better technology ((*e*)(1)(ii)(δ)).[23] Moreover, in those many cases where major deposits had been worked for centuries, they were permeated with shafts and tunnels, all unrecorded, that made the introduction of modern, large-scale workings difficult if not dangerous.

The unpredictability of the Chinese deposits seems also to have coalesced with the Chinese fondness for gambling to encourage a kind of lottery approach to mining.[24] Even the best mining methods cannot change the highly risky nature of mining. The Spanish proverb tells us that: 'La mineria es una loteria.'[25] Or, as Ricardo Godoy has put it: 'In mining, payoffs are more a matter of chance than of choice.' But good methods can certainly mitigate those risks. The Chinese seem to have ignored those better methods in all too many cases, even when the costs would have been minimal, and to have trusted instead to luck or help from the spirits ((*k*)(4)).[26]

Finally, the way the Chinese economy especially in recent centuries made use of a vast supply of cheap rural labour also often encouraged small-scale, primitive mining. Small-scale operations could easily cut back their production when market demand flagged and, as was usually the case, there was no possibility of finding alternative markets. When demand revived, operations could rapidly be expanded. Even well into this century, large coal mining companies frequently divided their operations into many small pits precisely because that allowed rapid expansion or contraction of activites in response to economic conditions.[27]

[22] In part because it was often difficult to predict how much capital would be necessary to bring a mine into production, the government was careful when assigning mining rights to select those entrepreneurs with substantial capital resources (see Section (*l*)).

[23] On the other hand, the case can be made that the achievements of the larger mining enterprises of the later imperial period were primarily organisational. In that, they are representative of a long Chinese tradition of mass mobilisation of labour whose beginnings can be seen already in the massive tomb complexes and other constructions of the Shang period (c. –1520 to c. –1030); Keightley (1972), pp. 125–40.

[24] Where it was in use, payment by shares of production (instead of by wages or a fixed piecework schedule) probably gave further stimulus to this kind of thinking and action; Thompson (1966), p. 358.

[25] Young (1970), p. 87.

[26] For an example of how an overemphasis on luck in mining could impede rational exploitation of ore deposits, recall the comments of Torgasheff above, Section (*f*)(3).

[27] Wright (1984), pp. 20–1. The many pits also facilitated use of the labour contractor system, thus minimising capital needs when expanding.

In summary then, Chinese mining in traditional times made use of a body of knowledge and a variety of practices at least as great as that found in any other technology in China, and probably greater than that to be found in *premodern* mining elsewhere. With all that variety, however, mining technology remained on the whole very primitive. Inadequate means for codifying and transmitting mining knowledge, the nature of the technology itself, and the conditions of Chinese society all interacted to set very real limits on the extent to which Chinese miners would use even the best available traditional techniques, while effectively precluding movement toward those techniques associated with more modern forms of mining.

BIBLIOGRAPHIES

A CHINESE AND JAPANESE BOOKS BEFORE +1800, AND ALL GAZETTEERS

B CHINESE AND JAPANESE BOOKS AND JOURNAL ARTICLES SINCE +1800, EXCLUDING GAZETTEERS

C BOOKS AND JOURNAL ARTICLES IN WESTERN LANGUAGES

Unlike earlier volumes, Bibliographies A and B here follow the Roman alphabetical sequence without exceptions for words beginning with Chh- or Hs-. The same is true, as before, for Bibliography C.

When obsolete or unusual romanisations of Chinese words occur in entries in Bibliography C, they are followed, wherever possible, by the romanisations adopted as standard in the present work. If inserted in the title, these are enclosed in square brackets; if they follow it, in round brackets. When Chinese words or phrases occur romanised according to the Wade–Giles system or related systems, they are assimilated to the system here adopted (cf. Vol. 1, p. 26) without indication of any change. Additional notes are added in round brackets.

Dates in italics imply that the work is in one or other of the East Asian languages.

Please note that the old system of reference numbers has been discontinued in favour of giving year of publication. This has become necessary in view of the difficulty of eliminating inconsistencies in the application of the previous system.

JOURNAL ABBREVIATIONS

See also p. xx

AA	*Artibus Asiae*
AHES/AESC	*Annales; Economies, Sociétés, Civilisations*
AI/AO	*Ars Orientalis* (formerly *Ars Islamica*)
AJA	*American Journal of Archaeology*
AM	*Asia Major*
AMA	*American Antiquity*
AMS	*American Scholar*
ANM	*Annales des Mines*
AO	*Acta Orientalia*
AQ	*Antiquity*
ARM	*Archaeomaterials*
ARSI	*Annual Reports of the Smithsonian Institution* (Washington, D.C.)
AS/BIHP	*Bulletin of the Institute of History and Philology, Academia Sinica (Chung-Kuo Kho Hsüeh Yen Chiu Yuan, Li-Shih Yü-Yen Yen Chiu So Chi Khan)*
ASEA	*Asiatische Studien; Études Asiatiques*
AX	*Ambix*
BGSC	*Bulletin of the Chinese Geological Survey*
BMFEA	*Bulletin of the Museum of Far Eastern Antiquities* (Stockholm)
BMM/S	*Bulletin of the Metals Museum* (Sendai)
BOCSHK	*Bulletin of the Oriental Ceramic Society of Hong Kong*
BSOAS	*Bulletin of the School of Oriental and African Studies*
CA	*Chemical Abstracts*
CAN	*Current Anthropology*
CCJ	*Chung-Chi Journal* (Chhung-Chi Univ. Coll. Hongkong)
CCUL	*Chinese Culture* (Thaipei)
CEJ	*Chinese Economic Journal*
CEM	*Chinese Economic Monthly* (Shanghai)
CG	*China Geographer*
CGU	*Colliery Guardian*
CHKK	*Chiang-Han Khao-Ku*
CHWSLT	*Chung-Hua Wên-Shih Lun Tshung (Collected Studies in the History of Chinese Literature)*
CHWW	*Chiang-Hsi Wen Wu*
CKCP	*Chung-Kuo Chhien-Pi*
CKKC	*Chung-Kuo Kho-Hsüeh Chi-Shu Fa-Ming Ho Kho-Hsüeh Chi-Shu Jen-Wu Lun Chi* (Essays on Chinese Discoveries and Inventions of Science and Technology, and on the Men who Made Them. Peking, 1955)
CKKCSL	*Chung-Kuo Kho-Chi Shih-Liao*
CKSHCCCK	*Chung-Kuo She-Hui Kho-Hsueh Yuan Ching-Chi Yen-Chiu So Chi-Khan*
CKSHCCSCK	*Chung-Kuo She-Hui Ching-Chi Shih Chi-Khan*
CKSHCCSLT	*Chung-Kuo She-Hui Ching-Chi Shih Lun-Tshung*
CKSHCCSYC	*Chung-Kuo She-Hui Ching-Chi Shih Yen-Chiu*
CKSYC	*Chung-Kuo Shih Yen-Chiu (Research in Chinese History)*
CKWHYCSHP	*Chung-Kuo Wen-Hua Yen-Chiu So Hsueh-Pao* (Hong Kong)
CNKK	*Chiang-Nan Khao-Ku*
CNWW	*Chiang-Nan Wen Wu*
CREC	*China Reconstructs*
CRRR	*Chinese Repository*
CS	*Current Science*
CSA	*Chinese Sociology and Anthropology*
CSC	*Chinese Science*
CSSH	*Comparative Studies in Society and History*
CSWT	*Chhing Shih Wen-Thi*
CYYK	*Chung-Yang Yen-Chiu Yuan Yuan-Khan*
D	*Discovery*
DA	*Der Anschnitt*
EC	*Early China*
EEH	*Explorations in Economic History*
EG	*Economic Geology*
EHR	*Economic History Review*
EM	*Engineering Magazine*
EMJ	*Engineering and Mining Journal*
EN	*Engineer*
END	*Endeavour*
FCLT	*Fu-Chien Lan-Than (Fukien Forum)*
FEQ	*Far Eastern Quarterly* (continued as *Journal of Asian Studies*)
FER	*Far Eastern Review* (London)
FMNHP/AS	*Field Museum of Natural History (Chicago) Publications*; Anthropological Series
GER	*Geologic Review*
GHA	*Göteborgs Högskolas Årskrift*
GJ	*Geographical Journal*
H	*History*
HCSYC	*Hai-Chiao Shih Yen-Chiu*
HCTHHP	*Hang-Chou Ta-Hsüeh Hsüeh-Pao (Hangchou University Journal)*
HHSTH	*Hua-Hsüeh Thung-Hsün (Chemical Correspondent)*, Chekiang Univ.
HHTP	*Hua-Hsüeh Thung-Pao* (*Chemical Intelligencer*), (Peking)
HHYC	*Han-Hsueh Yen-Chiu*
HJAS	*Harvard Journal of Asiatic Studies*
HM	*Historical Metallurgy*
HOT	*History of Technology* (annual)
HSYC	*Hsueh-Shu Yen-Chiu* (Yunnan)
HT	*History of Technology*
HYHP	*Hsin Ya Hsueh-Pao*
HYSYHSNK	*Hsin Ya Shu-Yuan Hsueh-Shu Nien-Khan*

IAR	Industrial Archaeology
ISIS	Isis
JA	Journal Asiatique
JAOS	Journal of the American Oriental Society
JAS	Journal of Asian Studies (continuation of Far Eastern Quarterly, FEQ)
JAUOS	Journal of the Australian Oriental Society
JEEH	Journal of European Economic History
JEH	Journal of Economic History
JESHO	Journal of the Economic and Social History of the Orient
JHMS	Journal of the Historical Metallurgy Society
JOSHK	Journal of Oriental Studies, Hongkong University
JRAI	Journal of the Royal Anthropological Institute
JRAS/NCB	Journal of the North China Branch of the Royal Asiatic Society
JRS	Journal of Roman Studies
JRSA	Journal of the Royal Society of Arts
JWCI	Journal of the Warburg and Courtauld Institutes
KCSWC	Kho-Chi Shih Wen Chi
KHS	Kho-Hsüeh (Science)
KHSC	Kho-Hsüeh Shih Chi-Khan (Ch. Journal Hist. of Sci.)
KHTP	Kho-Hsüeh Thung Pao (Scientific Correspondent)
KK	Khao-Ku (Archaeology)
KKHP	Khao-Ku Hsüeh-Pao (Archaeological Bulletin) (Peking)
KKTH	Khao-Ku Thung-Hsün (Archaeological Correspondent), cont. as Khao-Ku, KK.
KKWW	Khao-Ku Yü Wen Wu (Sian)
KKYK	Ku-Kung Po-Wu-Yüan Yüan-Khan (Peking)
KYCS	Khuang-Yeh Chi-Shu
LHHP	Li-Hsüeh Hsüeh-Pao (Journal of Physics)
LIC	Late Imperial China
LSTL	Li-Shih Ti-li
LSYC	Li-Shih Yen-Chiu (Peking) (Journal of Historical Research)
MA	Man
MAU	Materials Australasia
MCB	Mélanges Chinois et Bouddhiques
MCGS	Memoirs of the Chinese Geological Society
MCHSAMUC	Mémoires concernant l'Histoire, les Sciences, les Arts, les Mœurs et les Usages, des Chinois, par les Missionaires de Pékin, Paris, 1776–1814
MCM	Macmillan's Magazine
ME	Mining Engineering
MIMG	Mining Magazine
MINGS	Ming Studies
MJ	Mining Journal
MM	Mining and Metallurgy (New York, cont. as Mining Engineering)
MODC	Modern China
MS	Monumenta Serica
MSP	Mining and Scientific Press
MUS	Museum (Paris: UNESCO)
NC	Numismatic Chronicle (and Journal Roy. Numismatic Soc.)
NCH	North China Herald
NYKK	Nung-Yeh Khao-Ku (Agricultural Archaeology)
ORA	Oriental Art
ORI	Orientations
PAC	Pacific Affairs
PC	People's China
PHY	Physis (Florence)
PKCS	Pai Kho Chih Shih (Peking)
PKH	Pei-ching Kang-Thieh Kung-Yeh Hsueh-Yuan Hsueh-Pao
PNHB	Peking Natural History Bulletin
POPS	Popular Science (U.S.A.)
PP	Past and Present
RGKK	Rekishigaku Kenkyū
RI	Revue Indochinoise
SAM	Scientific American
SC	Science
SCK	Smithsonian Contributions to Knowledge
SCON	Studies in Conservation (Journal Internat. Instit. for the Conservation of Museum Objects)
SGZ	Shigaku Zasshi (Historical Journal) (Tokyo)
SHKH	She-Hui Kho-Hsüeh (Shanghai)
SHS	Studia Historica Slovaca
SMCK	Shu-Mu Chi-Khan
STYG	Shū kan Tōyōgaku
SV	Studi Veneziani
SYY	Ssu Yü Yen
TAIME	Trans. American Inst. Mining Engineers (continued as TAIMME)
TAIMME	Transactions of the American Institute of Mining and Metallurgical Engineers (formerly TAIME)
TCKH	Ti-Chhiu Kho-Hsueh
TCULT	Technology and Culture
TFIME	Trans. Federated Institution of Mining Engineers (cont. as TIME)
TG/K	Tōhō Gakuhō, Kyōto (Kyoto Journal of Oriental Studies)
TGE	Technikgeschichte
THTC	Ti-Hsüeh Tsa-Chih (Geographical Miscellany)
TICOJ	Transactions of the International Conference of Orientalists in Japan
TIME	Transactions of the Institution of Mining Engineers
TIMM	Transactions of the Institution of Mining and Metallurgy
TJKHSYC	Tzu-Jan Kho-Hsüeh Shih Yen-Chiu
TNS	Transactions of the Newcomen Society
TNWH	Tung-nan Wen-Hua
TP	T'oung Pao (Archives concernant l'Histoire, les Langues, la Géographie, l'Ethnographie et les Arts de l'Asie Orientale, Leiden)
TRP	Transpacifica
TYG	Tōyō Gakuhō (Reports of the Oriental Society of Tokyo)
TYSKK	Tōyōshi Kenkyū
W	Weather

WARC	*World Archaeology*
WHTHHP	*Wu-han Ta-Hsueh Hsueh-Pao*
WSC	*Wen Shih Che (Literature, History and Philosphy*, Shantung University, Tsingtao)
WW	*Wen Wu*: see *WWTK*
WWTK	*Wen Wu Tshan-Khao Tzu-Liao (Reference Materials for History and Archaeology)*: later *WW*
WWTLTK	*Wen Wu Tzhu-Liao Tshung-Khan*
WWYC	*Wen Wu Yen-Chiu*
YK	*Yü Kung (Chinese Journal of Historical Geography)*
YSCS	*Yu-Se Chin-Shu*

A. CHINESE AND JAPANESE BOOKS BEFORE +1800

Each entry gives particulars in the following order:
(*a*) title, alphabetically arranged, with characters;
(*b*) alternative title, if any;
(*c*) translation of title;
(*d*) cross-reference to closely related book, if any;
(*e*) dynasty;
(*f*) date as accurate as possible;
(*g*) name of author or editor, with characters;
(*h*) title of other book, if the text of the work now exists only incorporated therein; or, in special cases, references to sinological studies of it;
(*i*) references to translations, if any, given by the name of the translator in Bibliography C;
(*j*) notice of index or concordance;
(*k*) reference to the number of the book in the *Tao Tsang* catalogue of Wieger (1911), if applicable (*TT*);
(*l*) reference to the number of the book in the *San Tsang* (Tripitaka) catalogues of Nanjio and Takakusa & Watanabe, if applicable.

Words which assist in the translation of titles are added in round brackets.

Alternative titles or explanatory additions to the titles are added in square brackets.

The language of translations into languages other than modern Chinese and English is indicated.

Information on editions is given except in those cases where citations to the work are drawn only from secondary sources, which are cited in the footnotes.

ABBREVIATIONS

C/Han	Former Han.
E/Wei	Eastern Wei.
H/Han	Later Han.
H/Shu	Later Shu (Wu Tai).
H/Thang	Later Thang (Wu Tai).
H/Chin	Later Chin (Wu Tai).
S/Han	Southern Han (Wu Tai).
S/Phing	Southern Phing (Wu Tai).
J/Chin	Jurchen Chin.
L/Sung	Liu Sung.
N/Chou	Northern Chou.
N/Chhi	Northern Chhi.
N/Sung	Northern Sung (before the removal of the capital to Hangchow).
N/Wei	Northern Wei.
S/Chhi	Southern Chhi.
S/Sung	Southern Sung (after the removal of the capital to Hangchow).
W/Wei	Western Wei.

Chang-chhüan Kao 章全稿.
The Drafts of Chao Fan (*hao* Chang-chhüan).
S/Sung.
Chao Fan 趙蕃 (+1143 to +1229).

Chang-te Chih 彰德志.
The Gazetteer of Chang-te.
Ming, +16th.
Tshui Hsien 崔銑 (+1478 to +1541).

Chao Yü Chih 肇域志.
A Compendium of Historical Geography.
Chhing, +17th
Ku Yen-wu 顧炎武.
Never printed but survives in a number of manuscript versions; see Hummel (1943), Vol. 1, p. 424 and Chhen Lü-fan (*1980*), p. 21.

Che-chiang Thung Chih 浙江通志.
A Comprehensive Gazetteer of Che-chiang.
[= *Chhih Hsiu Che-chiang Thung Chih* (q.v.).]

Cheng Lei Pen Tshao 證類本草.
See *Ching-Shih Cheng Lei Pei-Chi Pen Tshao* and *Chhung-Hsiu Cheng-ho Ching-Shih Cheng Lei Pei-Yung Pen Tshao*.

Chhien Han Shu 前漢書.
History of the Former Han Dynasty [−206 to +24].
H/Han (begun about +65), c. +100.
Pan Ku 班固, and (after his death in +92) his sister Pan Chao 班昭.
Partial trs. Dubs (1938) and Swann (1974).
Chung-hua Shu-chü 1962 (punc.) ed.

Chhien Hung Chia Keng Chih Pao Chi Chheng 鉛汞甲庚至寶集成.
Complete Compendium on the Perfected Treasure of Lead, Mercury, Wood and Metal [with illustrations of alchemical apparatus].
On the translation of this title, see Vol. 5, pt. 3.
Has been considered Thang, +808; but perhaps more probably Wu Tai or Sung. See Vol. 5, pt. 5, p. 276.
Chao Nai-an 趙耐菴.
TT/912.

Chhih Hsiu Che-chiang Thung Chih 敕修浙江通志.
A Comprehensive Gazetteer of Che-chiang Compiled under Imperial Order.
Chhing, +1736.
Compiled by Li Wei 李衛 *et al.*

Chhin-Ting Hsü Wen-Hsien Thung Khao 欽定續文獻通考.
Imperially Commissioned Continuation of the *Comprehensive Study of (the History of) Civilisation* (See *Wen-Hsien Thung Khao* and *Hsü Wen-Hsien Thung Khao*).
Chhing, ordered in +1747, pr. +1772 (+1784).
Ed. Chhi Shao-nan 齊召南, Chi Huang 嵇璜 *et al.*
This parallels, but does not replace, Wang Chhi's *Hsü Wen-Hsien Thung Khao*.
Taiwan reprint of the Palace edition, 1963.

Chhing Po Tsa Chih 清波雜志.
Miscellaneous Notes [by One Living near the] Chhing-po Gate.
S/Sung, +1192.
Chou Hui 周輝.
Pi Hai ed.

Chhun Ming Meng Yü Lu 春明夢餘錄.
Surviving Notes of a Dream of the Capital.
Chhing, after +1654.
Sun Chheng-tse 孫承澤 (+1593 to +1675).
Chhün Shu Khao Suo 群書考索.
[= *Shan-thang Hsien-sheng Chhün Shu Khao Suo* (q.v.)]
Chhung Hsiu Cheng-ho Ching-Shih Cheng Lei Pei-Yung Pen Tshao 重修政和經史證類備用本草.
New Revision of the Materia Medica of the Cheng-ho Reign-period; the Classified and Consolidated Armamentarium. (A combination of the *Cheng-ho* . . . *Cheng Lei* . . . *Pen Tshao* with the *Pen Tshao Yen I*.)
Yuan, +1249; reprinted many times afterwards, esp. in the Ming.
Thang Shen-wei 唐愼微.
Khou Tsung-shih 寇宗奭.
Pr. (or ed.) Chang Tshun-hui 叔存惠.
Jen-min Wei-sheng Chhu-pan She 1957 ed.
See Unschuld (1986), 81–2.
Chi Chung Chou Shu 汲冢周書.
The Books of (the) Chou Dynasty found in the Tomb at Chi.
[= *I Chou Shu* (q.v.).]
Chi Ni Tzu 計倪子.
See *Fan Tzu Chi Jan*.
Chiang-hsi Thung Chih 江西通志.
Comprehensive Gazetteer of Chiang-hsi.
Chhing, 1880.
Compiled by Liu Khun-i 劉坤一 *et al.*
Chiang-nan Thung Chih 江南通志.
Comprehensive Gazetteer of Chiang-nan.
Chhing, +1736.
Compiled by Yin Chi-shan 尹繼善 *et al.*
Chien Chih Pien 見只編.
A Compilation of Things Seen.
Late Ming, before +1623.
Yao Shih-Lin 姚士麟 (Tzu: Shu-hsiang 叔祥)
Chien-yen I-Lai Chhao Yeh Tsa Chi 建炎以來朝野雜記.
Miscellaneous Notes On Court and Provinces Since the Chien-yen (+1127 to +1130) Period.
S/Sung, +13th.
Li Hsin-chhuan 李心傳.
Wen-hai, Taipei, 1967 repr.
See Hervouet (1978), 179–80.
Chien-yen I-Lai Hsi-Nien Yao-Lu 建炎以來繫年要錄.
A Record of Important Affairs Since the Chien-yen (+1127 to +1130) Period.
S/Sung, +13th
Li Hsin-chhuan 李心傳.
Wen-hai, Taipei, 1967 repr.
See Hervouet (1978), p. 81.
Chin Shih Pu Wu Chiu Shu Chüeh 金石簿五九數訣
Explanation of the Inventory of Metals and Minerals according to the Numbers Five (Earth) and Nine (Metal) [catalogue of substances with provenances, including some from foreign countries].
Thang, perhaps c. + 670 (contains a story relating to +664).
Writer unknown.
TT/900.
Chin Thung Yao-Lueh 浸銅要略.
Essentials of Steeping Copper.
N/Sung, c. +1095
Chang Chhien 張潛.
Lost during or after the Yuan.
Chin Thung Yao-Lueh Hsu 浸銅要略序.
Preface to the 'Essentials of Steeping Copper'
Yuan.
Wei Su 危素.
Included in *Wei Thai-phu Wen Chi*, ch. 10.
Ching-Shih Cheng Lei Pei-Chi Pen Tshao 經史證類備急本草.
The Classified and Consolidated Armamentarium of Pharmaceutical Natural History.
Sung, +1083, repr. +1090.
Thang Shen-wei 唐愼微.
See Unschuld (1986), 70–1.
Chiu Thang Shu 舊唐書.
Old History of the Thang Dynasty [+618 to +906].
Wu Tai (H/Chin), +945.
Liu Hsiu 劉昫.
Chung-hua Shu-chü 1975 (punc.) ed.
Chou I Tshan Thung Chhi 周易參同契.
The Accordance of the Book of Changes with the Phenomena of Composite Things (The Kinship of Three).
H/Han, +142.
Wei Po-yang 魏伯陽.
Chou Li 周禮.
Record of the Institutions (lit. Rites) of (the) Chou (Dynasty) [descriptions of all government official posts and their duties].
C/Han, probably containing some material from the late Chou; see Shih Ching-chheng (*1971*) especially for dating of *Khao Kung Chi* 考工記 (Artificers' Record) section.
Compilers unknown.
Lin Yin (1985) ed.
Tr. E. Biot (1851).
See Loewe (1993), 94–9.
Chou Shu 周書.
Records of the Chou (Dynasty).
[= *I Chou Shu* (q.v.)]

Erh Ya 爾雅.
The Literary Expositor.
Chou material, stabilised in Chhin or C/Han.
Compiler unknown.
Enlarged and commented on *c.* +300 by Kuo Pho 郭璞.
Yin-Te Index no. (suppl.) 18.
See Loewe (1993), 94–9.

Fan Tzu Chi Jan 范子計然.
[= *Chi Ni Tzu* 計倪子.]
The Book of Master Chi, by Master Fan.
Chou (Yueh), –4th century.
Attrib. Fan Li 范蠡, recording the philosophy of his master, Chi Jan 計然.
Fang Yü Sheng Lan 方輿勝覽.
A Geography for Visiting Spots of Scenic Beauty.
S/Sung, +13th.
Chu Mu 祝穆.
See Hervouet (1978), 130–1.

Han Pin Chi 漢濱集.
The Collected Works of Wang Chih-wang.
S/Sung, +12th.
Wang Chih-wang 王之望.
Ssu-khu chhüan-shu chen pen ed.
Hou Han Shu 後漢書.
History of the Later Han Dynasty [+25 to +220].
L/Sung, +450.
Fan Yeh 范曄.
The monograph chapters are by Ssuma Piao 司馬彪 (d. +305), with commentary by Liu Chao 劉昭 (c. +500), who first incorporated them into the work.
Chung-hua Shu-chü 1965 (punc.) ed.
Hsien-Yuan Pao Tsang Chhang Wei Lun 軒轅寶藏暢微論.
The Yellow Emperor's Expansive yet Detailed Discourse on the (Contents of the) Precious Treasury (of the Earth) [mineralogy and metallurgy]
Alternative title of *Pao Tshang Lun* (q.v.).
Hsien-Yuan Pao Tsang Lun 軒轅寶藏論
The Yellow Emperor's Discourse on the Contents of the Precious Treasury (of the Earth).
See *Pao Tshang Lun.*
Hsin Hsiu Pen Tshao 新修本草.
The New (lit. Newly Improved) Materia Medica.
Thang, +659.
Ed., Su Ching (= Su Kung) 蘇敬(蘇恭) and a commission of 22 collaborators under the direction first of Li Chi 李勣 and Yü Chih-ning 于志寧, then of Chhang-sun Wu-chi 長孫無忌. This work was afterwards commonly but incorrectly known as the *Thang Pen Tshao*. It was lost in China, apart from MS. fragments at Tunhuang, but copied by a Japanese in +731 and preserved in Japan, though incompletely.
See Unschuld (1986), 44–50.
Hsin Thang Shu 新唐書.
New History of the Thang Dynasty [+618 to +906].
Sung, +1061.
Ouyang Hsiu 歐陽修 and Sung Chhi 宋祁.
Chung-hua Shu-chü 1975 (punc.) ed.
Hsu Han Shu 續漢書.
Supplement to the [Former] Han History.
San Kuo, +3rd century.
Hsieh Chheng 謝承.
Hsu Tzu Chih Thung Chien 續資治通鑑.
Continuation of the *Comprehensive Mirror for Aid in Government.*
Chhing, 1801.
Pi Yuan 畢沅.
Chung-hua Shu-chü (punc.) 1957 ed.
Hsu Tzu Chih Thung Chien Chhang Pien 續資治通鑑長編.
Collected Data for a Continuation of *The Comprehensive Mirror for Aid in Government.*
S/Sung, +1163 to +1183.
Li Tao 李燾.
Chung-hua Shu-chü (punc.) 1979–1990 ed.
See Hervouet (1978), 72–5.
Hsu Wen-Hsien Thung Khao 續文獻通考
Continuation of the *Comprehensive Study of (the History of) Civilisation* (See *Wen-Hsien Thung Khao* and *Chhin-Ting Hsu Wen-Hsien Thung Khao*).
Ming, finished +1586, pr. +1603.
Ed., Wang Chhi 王圻.
This covers the Liao, J/Chin, Yuan and Ming dynasties, adding some new material for the end of S/Sung from +1224 onwards.
Shih Thung ed., Taiwan repr. 1965.
Hsu Yun-nan Thung Chih [Kao] 續雲南通志(稿).
A [Draft] Continuation of the Comprehensive Gazetteer of Yun-nan.
Chhing, 1900.
Compiled by Wang Wen-shao 王文韶 *et al.*
Wen-hai, Taipei, 1966 repr.
Huai Nan Tzu 淮南子.
[= *Huai Nan Hung Lieh Chieh* 淮南鴻烈解.]
The Book of (the Prince of) Huai-nan.
C/Han, c. -120.
Written by the group of scholars gathered by Liu An 劉安 (prince of Huai-nan).
TT/1170.
Ssu-Pu Pei-Yao ed.
Huai-nan (Wang) Wan Pi Shu 淮南(王)萬畢術.
The Ten Thousand Infallible Arts of (the Prince of) Huai-nan.
C/Han, -2nd century.
No longer a separate book but fragments contained in *Thai-phing Yü-Lan*, ch. 736 and elsewhere.
Reconstitued texts by Yeh Te-hui in *Kuan Ku Thang So Chu Shu*, and Sun Feng-i in *Wen Ching Thang Tshung-Shu.*
Attrib. Liu An 劉安.
Huang Chhao Ching Shih Wen Pien 皇朝經世文編.
A Collection of Essays and Other Writings on Ordering the World.
Chhing, +1826; printed +1827.
Ho Chhang-ling 賀長齡.

I Chou Shu 逸周書.
[= *Chi Chung Chou Shu*]
Lost Records of the Chou (Dynasty).
Chou, -245 and before, such parts as are genuine. Found in the tomb of An Li Wang 安釐王 (r. -276 to -245), a prince of the Wei 魏 state, in +281.
Writers unknown.
Ssu-Pu Pei-Yao ed.
See Loewe (1993), 229–33.

Kai Yü Tshung Khao 陔餘叢考.
A Collection of Spare-time Studies While Caring for my Parents.
Chhing, +1790.
Chao I 趙翼.
Khai-pao [Hsin Hsiang-Ting] Pen Tshao 開寶[新詳定]本草.
Materia Medica [Newly Examined and Determined in] the Khai-pao [968–976] Reign-period.
Sung, +973.

Liu Han 劉翰, Ma Chih 馬志 and Lu To-hsun 盧多遜.
See Unschuld (1986), 55, 58.
Khao Kung Chi 考工記.
The Artificers' Record [a section of the *Chou Li*, q.v.]
Chou and Han, perhaps originally an official document of Chhi State, incorporated into the *Chou Li* c. −140.
Compiler unknown.
In Yin Lin (*1985*) ed. of *Chou Li*.
Tr. E. Biot (1851)
See Wagner (1993), 109–10; Loewe (1993), p. 25; Hsuan Chao-chhi (*1993*).
Khun Yü Ko Chih 坤輿格致.
Exhaustive Investigations of (the Contents of) the Earth [Adaptation into Chinese of Agricola's *De Re Metallica*].
Ming, c. +1640.
Thang Jo-wang 湯若望 (Johann Adam Schall von Bell).
Ko Ku Yao Lun 格古要論.
The Essential Criteria of Antiquities.
Ming, +1387 or +1388.
Tshao Chao 曹昭.
See Goodrich & Fang (1976), 1296–7.
Tr. David (1971).
Kuan Tzu 管子.
The Book of Master Kuan.
Chou and C/Han. Perhaps mainly compiled in the Chi-Hsia Academy (late −4th century) in part from older materials.
Attrib. Kuan Chung 管仲.
Ssu-Pu Pei-Yao ed.
Partial trs. Than Po-fu *et al.* (1954); Rickett (1985); Ma Fei-pai (*1979*).
See Loewe (1993), 244–51.
Kuei Erh (San) Chi 貴耳[三]集.
Collected Notes of an Invaluable Ear.
Sung, +1241 to +1248.
Chang Tuan-i 張端義.
Chin Tai Mi Shu 津逮秘書 ed.

Lei Kung Yao Tui 雷公藥對.
Answers of the Venerable Master Lei (to Questions) Concerning Drugs.
Perhaps L/Sung, at any rate before N/Chhi.
Attr. Lei Hsiao 雷斅.
Later attrib. to a legendary minister of Huang Ti.
Comm. by Hsu Chih-tshai 徐之才, N/Chhi +565.
Now extant only in quotations.
Ling Piao Lu I 嶺表錄異.
Southern Ways of Men and Things [on the special characteristics and natural history of Kwangtung].
Thang, c. +895.
Liu Hsun 劉恂.
Ling Wai Tai Ta 嶺外代答.
Information on What is Beyond the Passes (lit. a book in lieu of individual replies to questions from friends).
Sung, +1178.
Chou Chhü-fei 周去非.
Chih-Pu-Tsu Chi Tshung-Shu ed.
Tr. Netolitzky (1977) (German).
Lü Shih Chhun Chhiu 呂氏春秋.
Master Lü's Spring and Autumn Annals [compendium of natural philosophy].
Chou (Chhin), −239.
Written by a group of scholars gathered by Lü Pu-wei 呂不韋.
Ssu-Pu Pei-Yao ed.
Tr. R. Wilhelm (1928).
Chung-Fa index, no. 2.
Lun Heng 論衡.
Discourses Weighed in the Balance.
H/Han, between +70 and +80(?)
Wang Chhung 王充.
Tr. Forke (1907, 1911).
Pei-ching Ta-hsueh Li-shih-hsi (*1979*) ed.
See Loewe (1993), 309–12.
Lung-chhüan Hsien Chih 龍泉縣之.
A Gazetteer of Lung-chhüan County.
Ming or earlier; see Yoshida (*1967*), p. 237.
Author unknown.
This work is lost but is extensively cited in the *Chhih Hsiu Che-chiang Thung Chih*.
Lung Chhuan Lueh Chih 龍川略志.
[= *Su Huang-men Lung Chhuan Lueh Chih* (q.v.).]
Lung Hu Huan Tan Chueh 龍虎還丹訣.
Explanation of the Dragon-and-Tiger Cyclically Transformed Elixir.
Perhaps mid-Thang.
Chin Ling Tzu 金陵子.
TT/902.

Man Shu 蠻書.
Book of the [Southern] Barbarians.
Thang, c. +860.
Fan Chho 樊綽.
Tshung-Shu Chi-chheng ed.
Tr. Luce & Oey (1961).
Meng Chhi Pi Than 夢溪筆談.
Brush Talks from the Dream Brook.
Sung, +1086; last supplement dated +1091.
Shen Kua 沈括.
Hu Tao-ching (*1956*) ed. Taipei 1961 repr.
See Hervouet (1978), 226–8.
Ming Shih 明史.
History of the Ming Dynasty [+1368 to +1643].
Chhing, begun +1646, completed +1736, first pr. +1739.
Chang Thing-yü 張廷玉 *et al.*
Chung-hua Shu-chü 1974 (punc.) ed.

Pao Phu Tzu 抱樸(朴)子.
Book of the Preservation-of-Solidarity Master.
Chin, early +4th century.
Ko Hung 葛洪.
Ssu-Pu Tshung-Khan ed.

Pao Tshang Lun 寶藏論
[= *Hsien-Yuan Pao Tsang Chhang Wei Lun.*]
(The Yellow Emperor's) Discourse on the (Contents of the) Precious Treasury (of the Earth), [mineralogy and metallurgy].
Perhaps in part Thang or even as early as Chin (+3rd or +4th); completed in Wu Tai (S/Han).
Attrib. Chhing Hsia Tzu 青霞子
Now extant only in quotations.

Pen Tshao Ching Chi Chu 本草經集注.
Collected Commentaries on the *Classic of Pharmaceutics (of the Heavenly Husbandman)*.
S/Chhi, +492.
Now extant only in fragmentary form as a Tunhuang or Turfan MS., apart from the many quotations in the pharmaceutical natural histories, under Thao Hung-ching 陶弘景's name.
See Unschuld (1986), 30ff.

Pen Tshao Kang Mu 本草綱目.
The Great Materia Medica; or, The Pandects of Natural History (Mineralogy, Metallurgy, Botany, Zoology etc.), Arrayed in their Headings and Subheadings.
Ming, +1596.
Li Shih-chen 李時珍.
Shang-Wu, Hong Kong 1967 repr. of 1954 ed.
Much of the material on minerals and stones incorporated into Read & Pak (1928) and (1936), with indexes.
See Unschuld (1986), 142–63.

Pen Tshao Shih I 本草拾遺.
A Materia Medica Supplement.
Thang, c. +725.
Chhen Tshang-Chhi 陳藏器.
Now extant only in numerous quotations.

Pen Tshao Thu Ching 本草圖經.
Illustrated Materia Medica.
Sung, +1061.
Su Sung 蘇頌 *et al.*
Now preserved only in numerous quotations in the later pandects of pharmaceutical natural history.
See Unschuld (1986), 64–8.

Pen Tshao Yen I 本草衍義.
Dilations upon Pharmaceutical Natural History.
Sung, pref. +1116, pr. +1119, repr. +1185, +1195.
Khou Tsung-shih 寇宗奭.
Ta-Tung Shu-Chu, Shanghai 1936 ed.
See also *Thu Ching Yen I Pen Tshao* (*TT*/761).
See Unschuld (1986), 85–101.

Phing Chai Wen Chi 平齋文集.
The Collected Works of Hung Tzu-khuei.
S/Sung, +13th.
Hung Tzu-khuei 洪咨夔.
Ssu-Pu Tshung-Khan ed.

Phing-chou Kho Than 萍州可談.
From the Chats in Phing-chou
N/Sung, +1119 (referring to +1086 onwards).
Chu Yü 朱彧.
See Hervouet (1978), 333–4.
Shou-shan-ko tshung-shu ed.

Po-chai Pien 泊宅編.
A Compilation from Po-chai Village.
N/Sung, c. +1117 (mainly concerned with events from +1086 onwards).
Fang Shao 方勺.
See Hervouet (1978), p. 290, esp. on why *Tu-hua-chai tshung-shu* 讀畫齋叢書 ed. is definitely to be preferred.

Po Wu Yao Lan 博物要覽.
The Principal Points about Objects of Art and Nature.
Ming, c. +1560.
Ku Thai 谷泰.
Pai-Pu Tshung-Shu Chi-Chheng ed.

San Shih Liu Shui Fa 三十六水法.
Thirty-six Methods for Bringing Solids into Aqueous Solution.
Pre-Thang with Parts Probably Dating to Western Han; see Chhen Kuo-fu (*1982*), 315–16.
Author unknown.
TT/923.

San Yuan Ta Tan Mi Yuan Chen Chih 三元大丹秘苑真旨.
True Objectives from the Three Fundamentals Great Cinnabar Secret Garden.
Unknown, but first appears in the early Chhing *Wai Chin Tan* 外金丹 *tshung-shu* compiled and edited by Chhuan Chhüan-chhüan 傳全詮 (Chi I-tzu 濟一子); see Chao Khuang-hua (*1987*), p. 329.
Author unknown.

Shan Hai Ching 山海經.
Classic of the Mountains and Rivers.
Chou and C/Han.
Writers unknown (but see Wagner (1993), 248–50).
Yuan Kho (*1980*) ed.
Translations: Mathieu (1983) (French); Cheng Hsiao-chieh *et al.* (1985) (English).
See Wagner (1993), 248–50; Loewe (1993), 357–67.

Shan-hsi Thung Chih 陝西通志.
A Comprehensive Gazetteer of Shensi Province.
Chhing, +1735.
Liu Yü-i 劉於義.

[Shan-thang Hsien-sheng] Chhün Shu Khao Suo 山堂先生群書考索.
Mr. Shan-thang's Critical Compilation from a Myriad Sources.
S/Sung, +1210.
Chang Ju-yü 章如愚.
Hsin-Hsing Shu-Chü, Taipei, 1969 facsimile reprint of 1508 woodblock ed.
See Hervouet (1978) p. 327; Teng & Biggerstaff (1971), p. 90.

Shen Nung Pen Tshao Ching 神農本草經.
Classic of Pharmaceutics of the Heavenly Husbandman.
C/Han, based on Chou and Chhin material, but not reaching final form before the +2nd century.
Writers unknown.
Lost as a separate work, but the basis of all subsequent compendia of pharmaceutical natural history, in which it is constantly quoted.

Reconstituted and annotated by many scholars; see Lung Po-chien (*1957*), 2 ff., 12ff.
See Unschuld (1986), 17–27.

Shih Chi 史記.
Historical Records [or, Records of the Historiographer(-Royal); down to −99].
C/Han, c. −90.
Ssuma Chhien 司馬遷, and his father Ssuma Than 司馬談.
Chung-hua Shu-chü 1959 (punc.) ed.
Partial trans. Chavannes 1895–1905 (French); Watson (1993); Swann (1974); etc.
See Loewe (1993), 405–14.

Shih Thien Tsa Chi 石田雜記.
Shen Stone-Field's Miscellaneous Notes.
Ming, c. +1500 (?).
Shen Chou (*hao* Shih-thien) 沈周.

Shu Ching 書經.
Historical Classic [or, Book of Documents].
The 29 'Chin Wen' chapters mainly Chou (a few pieces possibly Shang); the 21 'Ku Wen' chapters a 'forgery' by Mei Tse 梅賾, c. +320, using fragments of genuine antiquity. Of the former, 13 are considered to go back to the −10th century, 10 to the −8th, and 6 not before the −5th. Some scholars accept only 16 or 17 as pre-Confucian.
Writers unknown.
Tr. Legge (1865); Karlgren (1950). Concordance by Ku Chieh-kang 顧頡剛; see Teng & Biggerstaff (1971), p. 216.

Shu Yuan Tsa Chi 菽園雜記.
Miscellaneous Notes from the Garden of Pulses.
Ming, +1475.
Lu Jung 陸容.
Kuang-Wen Shu-Chü, Taipei, 1970 repr. of Mo Hai Chin Hu 墨海金壺 1810 ed.

Shui Ching 水經.
The Waterways Classic [geographical account of rivers and canals].
Ascr. C/Han, prob. San Kuo.
Attrib. Sang Chhin 桑欽.

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See Hervouet (1978), 396–8.

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Thang, +636 (annals and biographies); +656 (monographs and bibliography).
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Chhiu Chün (d. +1495) 丘濬.

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Ming, c. +1461.
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Tshao Hsueh-chhüan 曹學佺.

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Gazetteer of Ta-thung Fu.
Chhing, Orig. ed. +1776; rev. ed. +1782.
Wang Fu-hung 王輔宏 (comp.) & Wang Fei-tsao 王飛藻 (ed.)

Tan Fang Chien Yuan 膽方鑑源.
The Mirror of Alchemical Processes (and Reagents); a Source-book.
Wu Tai (H/Shu), c. +938 to +965.
Tuku Thao 獨孤滔.
TT/918.

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The Mirror of the Alchemical Elaboratory; a Source-book.
Early Thang, not later than +800.
Writer unknown.
Survives only incorporated in *TT*/912 and in the *Cheng Lei Pen Tshao* (q.v.).

Tao Tsang 道藏.
The Taoist Patrology [containing 1464 Taoist works].
All periods, but first collected in the Thang about +730, then again about +870 and definitively in +1019. First printed in the Sung (+1111 to +1117).
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Authors numerous.
Indexes by Wieger (1911), on which see review in Pelliot (1912); and Ong Tu-chien (*1935*) (Yin-Te Index, no. 25).

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The Universal Geography of the Thai-phing Reign-period.
N/Sung, +976 to +983.
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See Hervouet (1978), p. 128.

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Imperial Encyclopedia of the Thai-phing [Hsing-kuo] Reign-period (reviewed by the Emperor before publishing).
Sung, +983.
Ed. Li Fang 李昉.
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Than Yuan 談苑.
An Anthology of Conversations.
N/Sung, late 11th.
Khung Phing-chung 孔平仲 (? See Miyashita (*1967*), p. 154, n. 40).

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Institutes of the Thang Dynasty (lit. Administrative Regulations of the Six Ministries of the Thang).
Thang, +738 or +739.
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Ssu-Khu Chhuan Shu ed.

Thang Pen Tshao 唐本草.
Materia Medica the Thang Dynasty.
[= *Hsin Hsiu Pen Tshao*, (q.v.).]

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The Characteristics (lit. Advantages and Disadvantages) of Each Province in the Empire.
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Ku Yen-wu 顧炎武.
Ssu-Pu Tshung-Khan ed.
See Wilkinson (1973), 107–8.

Thien Kung Khai Wu 天工開物.
The Exploitation of the Works of Nature.
Ming, +1637.
Sung Ying-hsing 宋應星.
See Phan Chi-hsing (*1986*).
Shih-Chieh, Taipei, 1962 ed.

Thu Ching Yen I Pen Tshao 圖經衍義本草.
Illustrations (and Commentary) for the *Dilations upon Pharmaceutical Natural History*. (An abridged conflation of the *Pen Tshao Yen I* with two other *Pen Tshao*.)
Sung, c. +1223.
Ed. Hsu Hung 許洪.
TT/761. (Ong Tu-chien (*1935*), no. 768.)

Thung Cheng Chhüan Shu 銅政全書.
Complete Copper Policies.
Chhing, compiled in +1787.
Wang Chhang 王昶.
The original work, in 50 ch., does not survive but it is extensively extracted in Wu Chhi-chün (*1845*) (q.v.).

Ti Ching Thu 地鏡圖.
Illustrated Mirror of the Earth.
Liang, +6th century.
Writer unknown.

Tien-nan Hsin Yü 滇南新語.
New Words from Yunnan.
Chhing.
Chang Hung 張泓.

Tshan Thung Chhi Wu Hsiang Lei Pi Yao 參同契五相類秘要.
Arcane Essentials of the Similarities and Categories of the Five (Substances) in the *Kinship of the Three* (sulphur, realgar, orpiment, mercury and lead).
Liu Chhao, possibly Thang; prob. between +6th and +8th centuries.
Comm. by Lu Thien-chi 盧天驥, wr. Sung, c. +1114.
TT/898.
Trans. Ho Ping-yü & Needham (1959).

Tso Chuan 左傳.
Master Tso Chhiu-ming's Tradition (or Enlargement) of the *Chhun Chhiu* (*Spring and Autumn Annals*) [dealing with the period −722 to −453].

Late Chou, compiled from ancient written and oral traditions of several states between −430 and −250, but with additions and changes by Confucian scholars of the Chhin and Han, especially Liu Hsin. Greatest of the three commentaries on the *Chhun Chhiu*, the others being the *Kungyang Chuan* and the *Kuliang Chuan*, but, unlike them, probably originally itself an independent book of history.
Attrib. Tso Chhiu-ming 左邱明.
See Egan (1977); Wang (1977); Loewe (1993), 67–76.
Tr. Couvreur (1914); Legge (1872); Watson (1989).

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The Essentials of Geography for the Reading of History.
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See Wilkinson (1973), p. 108; Hummel (1943), Vol. 1, p. 420.
Shanghai 1901 woodblock ed.

Wei Shu 魏書.
History of the (Northern) Wei Dynasty [+386 to +550], including the Eastern Wei Successor State.
N/Chhi, +554, revised +572.
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Fifty-two Prescriptions for Illness.
Pre-Han (text from Ma Wang Tui).
Author unknown.

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Sun Chiung 孫炯 (?).
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C/Han, c. −80 to −60.
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Elegant Conversations from the Academy.
Yuan, +1288.
Wang Yun 王惲.
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See Hervouet (1978), 194–5.

Yuan-feng Chiu Yü Chih 元豐九域志.
Gazetteer of the Nine Regions of the Yuan-feng Reign-period.
N/Sung, presented to the throne in +1080 and published officially in +1085.
Ed. Wang Tshun 王存 *et al.*
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Gazetteer of the Provinces and Counties of the Yuan-ho Period [+806 to +821].
Thang, after +814.
Li Chi-fu 李吉甫.
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S/Sung, +1206 (referring to events of about +1170 onwards).
Chao Yen-wei 趙彥衛.
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Comprehensive Gazetteer of Yun-nan.
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GENERAL INDEX

Note: page numbers in *italics* refer to figures and tables. Page numbers with suffix *n* refer to footnotes.

	夏	HSIA kingdom (legendary?)		c. −2000 to c. −1520
	商	SHANG (YIN) kingdom		c. −1520 to c. −1030
	周	CHOU dynasty (Feudal Age)	Early Chou period	c. −1030 to −722
			Chhun Chiu period 春秋	−722 to −480
			Warring States (Chan Kuo) period 戰國	−480 to −221
First Unification	秦	CHHIN dynasty		−221 to −207
	漢	HAN dynasty	Chhien Han (Earlier or Western)	−202 to +9
			Hsin interregnum	+9 to +23
			Hou Han (Later or Eastern)	+25 to +220
	三國	SAN KUO (Three Kingdoms period)		+211 to +265
First Partition	蜀	SHU (HAN)		+211 to +264
	魏	WEI		+200 to +265
	吳	WU		+222 to +280
Second Unification	晉	CHIN dynasty: Western		+265 to +317
		Eastern		+317 to +420
	劉宋	(Liu) SUNG dynasty		+420 to +479
Second Partition		Northern and Southern Dynasties (Nan Pei chhao)		
	齊	CHHI dynasty		+479 to +502
	梁	LIANG dynasty		+502 to +557
	陳	CHHÊN dynasty		+557 to +589
	魏	Northern (Thopa) WEI dynasty		+386 to +535
		Western (Thopa) WEI dynasty		+535 to +556
		Eastern (Thopa) WEI dynasty		+534 to +550
	北齊	Northern CHHI dynasty		+550 to +577
	北周	Northern CHOU (Hsienpi) dynasty		+557 to +581
Third Unification	隋	SUI dynasty		+581 to +618
	唐	THANG dynasty		+618 to +906
Third Partition	五代	WU TAI (Five Dynasty period) (Later Liang, Later Thang (Turkic), Later Chin (Turkic), Later Han (Turkic) and Later Chou)		+907 to +960
	遼	LIAO (Chhitan Tartar) dynasty		+907 to +1124
		West LIAO dynasty (Qarā-Khiṭāi)		+1124 to +1211
	西夏	Hsi Hsia (Tangut Tibetan) state		+986 to +1227
Fourth Unification	宋	Northern SUNG dynasty		+960 to +1226
	宋	Southern SUNG dynasty		+1127 to +1279
	金	CHIN (Jurchen Tartar) dynasty		+1115 to +1234
	元	YÜAN (Mongol) dynasty		+1260 to +1368
	明	MING dynasty		+1368 to +1644
	清	CHHING (Manchu) dynasty		+1644 to +1911
	民國	Republic		+1912

N.B. When no modifying term in brackets is given, the dynasty was purely Chinese. Where the overlapping of dynasties and independent states becomes particularly confused, the tables of Wieger (1) will be found useful. For such periods, especially the Second and Third Partitions, the best guide is Eberhard (9). During the Eastern Chin period there were no less than eighteen independent States (Hunnish, Tibetan, Hsienpi, Turkic, etc.) in the north. The term 'Liu chhao' (Six Dynasties) is often used by historians of literature. It refers to the south and covers the period from the beginning of the +3rd to the end of the +6th centuries, including (San Kuo) Wu, Chin, (Liu) Sung, Chhi, Liang and Chhen. For all details of reigns and rulers see Moule & Yetts (1).

ROMANISATION CONVERSION TABLES

BY ROBIN BRILLIANT

PINYIN/MODIFIED WADE-GILES

Pinyin	Modified Wade-Giles	Pinyin	Modified Wade-Giles
a	a	chu	chhu
ai	ai	chuai	chhuai
an	an	chuan	chhuan
ang	ang	chuang	chhuang
ao	ao	chui	chhui
ba	pa	chun	chhun
bai	pai	chuo	chho
ban	pan	ci	tzhu
bang	pang	cong	tshung
bao	pao	cou	tshou
bei	pei	cu	tshu
ben	pên	cuan	tshuan
beng	pêng	cui	tshui
bi	pi	cun	tshun
bian	pien	cuo	tsho
biao	piao	da	ta
bie	pieh	dai	tai
bin	pin	dan	tan
bing	ping	dang	tang
bo	po	dao	tao
bu	pu	de	tê
ca	tsha	dei	tei
cai	tshai	den	tên
can	tshan	deng	têng
cang	tshang	di	ti
cao	tsho	dian	tien
ce	tshê	diao	tiao
cen	tshên	die	dieh
ceng	tshêng	ding	ting
cha	chha	diu	tiu
chai	chhai	dong	tung
chan	chhan	dou	tou
chang	chhang	du	tu
chao	chhao	duan	tuan
che	chhê	dui	tui
chen	chhên	dun	tun
cheng	chhêng	duo	to
chi	chhih	e	ê, o
chong	chhung	en	ên
chou	chhou	eng	êng

Pinyin	Modified Wade-Giles	Pinyin	Modified Wade-Giles
er	êrh	jian	chien
fa	fa	jiang	chiang
fan	fan	jiao	chiao
fang	fang	jie	chieh
fei	fei	jin	chin
fen	fên	jing	ching
feng	fêng	jiong	chiung
fo	fo	jiu	chiu
fou	fou	ju	chü
fu	fu	juan	chüan
ga	ka	jue	chüeh, chio
gai	kai	jun	chün
gan	kan	ka	kha
gang	kang	kai	khai
gao	kao	kan	khan
ge	ko	kang	khang
gei	kei	kao	khao
gen	kên	ke	kho
geng	kêng	kei	khei
gong	kung	ken	khên
gou	kou	keng	khêng
gu	ku	kong	khung
gua	kua	kou	khou
guai	kuai	ku	khu
guan	kuan	kua	khua
guang	kuang	kuai	khuai
gui	kuei	kuan	khuan
gun	kun	kuang	khuang
guo	kuo	kui	khuei
ha	ha	kun	khun
hai	hai	kuo	khuo
han	han	la	la
hang	hang	lai	lai
hao	hao	lan	lan
he	ho	lang	lang
hei	hei	lao	lao
hen	hên	le	lê
heng	hêng	lei	lei
hong	hung	leng	lêng
hou	hou	li	li
hu	hu	lia	lia
hua	hua	lian	lien
huai	huai	liang	liang
huan	huan	liao	liao
huang	huang	lie	lieh
hui	hui	lin	lin
hun	hun	ling	ling
huo	huo	liu	liu
ji	chi	lo	lo
jia	chia	long	lung

Pinyin	Modified Wade-Giles	Pinyin	Modified Wade-Giles
lou	lou	ou	ou
lu	lu	pa	pha
lü	lü	pai	phai
luan	luan	pan	phan
lüe	lüeh	pang	phang
lun	lun	pao	phao
luo	lo	pei	phei
ma	ma	pen	phên
mai	mai	peng	phêng
man	man	pi	phi
mang	mang	pian	phien
mao	mao	piao	phiao
mei	mei	pie	phieh
men	mên	pin	phin
meng	mêng	ping	phing
mi	mi	po	pho
mian	mien	pou	phou
miao	miao	pu	phu
mie	mieh	qi	chhi
min	min	qia	chhia
ming	ming	qian	chhien
miu	miu	qiang	chhiang
mo	mo	qiao	chhiao
mou	mou	qie	chhieh
mu	mu	qin	chhin
na	na	qing	chhing
nai	nai	qiong	chhiung
nan	nan	qiu	chhiu
nang	nang	qu	chhü
nao	nao	quan	chhüan
nei	nei	que	chhüeh, chhio
nen	nên	qun	chhün
neng	nêng	ran	jan
ng	ng	rang	jang
ni	ni	rao	jao
nian	nien	re	jê
niang	niang	ren	jên
niao	niao	reng	jêng
nie	nieh	ri	jih
nin	nin	rong	jung
ning	ning	rou	jou
niu	niu	ru	ju
nong	nung	rua	jua
nou	nou	ruan	juan
nu	nu	rui	jui
nü	nü	run	jun
nuan	nuan	ruo	jo
nüe	nio	sa	sa
nuo	no	sai	sai
o	o, ê	san	san

Pinyin	Modified Wade-Giles	Pinyin	Modified Wade-Giles
sang	sang	tuo	tho
sao	sao	wa	wa
se	sê	wai	wai
sen	sên	wan	wan
seng	sêng	wang	wang
sha	sha	wei	wei
shai	shai	wen	wên
shan	shan	weng	ong
shang	shang	wo	wo
shao	shao	wu	wu
she	shê	xi	hsi
shei	shei	xia	hsia
shen	shen	xian	hsien
sheng	shêng, sêng	xiang	hsiang
shi	shih	xiao	hsiao
shou	shou	xie	hsieh
shu	shu	xin	hsin
shua	shua	xing	hsing
shuai	shuai	xiong	hsiung
shuan	shuan	xiu	hsiu
shuang	shuang	xu	hsü
shui	shui	xuan	hsüan
shun	shun	xue	hsüeh, hsio
shuo	shuo	xun	hsün
si	ssu	ya	ya
song	sung	yan	yen
sou	sou	yang	yang
su	su	yao	yao
suan	suan	ye	yeh
sui	sui	yi	i
sun	sun	yin	yin
suo	so	ying	ying
ta	tha	yo	yo
tai	thai	yong	yung
tan	than	you	yu
tang	thang	yu	yü
tao	thao	yuan	yüan
te	thê	yue	yüeh, yo
teng	thêng	yun	yün
ti	thi	za	tsa
tian	thien	zai	tsai
tiao	thiao	zan	tsan
tie	thieh	zang	tsang
ting	thing	zao	tsao
tong	thung	ze	tsê
tou	thou	zei	tsei
tu	thu	zen	tsên
tuan	thuan	zeng	tsêng
tui	thui	zha	cha
tun	thun	zhai	chai

Pinyin	Modified Wade-Giles	Pinyin	Modified Wade-Giles
zhan	chan	zhuan	chuan
zhang	chang	zhuang	chuang
zhao	chao	zhui	chui
zhe	chê	zhun	chun
zhei	chei	zhuo	cho
zhen	chên	zi	tzu
zheng	chêng	zong	tsung
zhi	chih	zou	tsou
zhong	chung	zu	tsu
zhou	chou	zuan	tsuan
zhu	chu	zui	tsui
zhua	chua	zun	tsun
zhuai	chuai	zuo	tso

MODIFIED WADE-GILES/PINYIN

Modified Wade-Giles	Pinyin	Modified Wade-Giles	Pinyin
a	a	chhing	qing
ai	ai	chhio	que
an	an	chhiu	qiu
ang	ang	chhiung	qiong
ao	ao	chho	chuo
cha	zha	chhou	chou
chai	zhai	chhu	chu
chan	zhan	chhuai	chuai
chang	zhang	chhuan	chuan
chao	zhao	chhuang	chuang
chê	zhe	chhui	chui
chei	zhei	chhun	chun
chên	zhen	chhung	chong
chêng	zheng	chhü	qu
chha	cha	chhüan	quan
chhai	chai	chhüeh	que
chhan	chan	chhün	qun
chhang	chang	chi	ji
chhao	chao	chia	jia
chhê	che	chiang	jiang
chhên	chen	chiao	jiao
chhêng	cheng	chieh	jie
chhi	qi	chien	jian
chhia	qia	chih	zhi
chhiang	qiang	chin	jin
chhiao	qiao	ching	jing
chhieh	qie	chio	jue
chhien	qian	chiu	jiu
chhih	chi	chiung	jiong
chhin	qin	cho	zhuo

Modified Wade-Giles	Pinyin	Modified Wade-Giles	Pinyin
chou	zhou	hu	hu
chu	zhu	hua	hua
chua	zhua	huai	huai
chuai	zhuai	huan	huan
chuan	zhuan	huang	huang
chuang	zhuang	hui	hui
chui	zhui	hun	hun
chun	zhun	hung	hong
chung	zhong	huo	huo
chü	ju	i	yi
chüan	juan	jan	ran
chüeh	jue	jang	rang
chün	jun	jao	rao
ê	e, o	jê	re
ên	en	jên	ren
êng	eng	jêng	reng
êrh	er	jih	ri
fa	fa	jo	ruo
fan	fan	jou	rou
fang	fang	ju	ru
fei	fei	jua	rua
fên	fen	juan	ruan
fêng	feng	jui	rui
fo	fo	jun	run
fou	fou	jung	rong
fu	fu	ka	ga
ha	ha	kai	gai
hai	hai	kan	gan
han	han	kang	gang
hang	hang	kao	gao
hao	hao	kei	gei
hên	hen	kên	gen
hêng	heng	kêng	geng
ho	he	kha	ka
hou	hou	khai	kai
hsi	xi	khan	kan
hsia	xia	khang	kang
hsiang	xiang	khao	kao
hsiao	xiao	khei	kei
hsieh	xie	khên	ken
hsien	xian	khêng	keng
hsin	xin	kho	ke
hsing	xing	khou	kou
hsio	xue	khu	ku
hsiu	xiu	khua	kua
hsiung	xiong	khuai	kuai
hsü	xu	khuan	kuan
hsüan	xuan	khuang	kuang
hsüeh	xue	khuei	kui
hsün	xun	khun	kun

Modified Wade-Giles	Pinyin	Modified Wade-Giles	Pinyin
khung	kong	min	min
khuo	kuo	ming	ming
ko	ge	miu	miu
kou	gou	mo	mo
ku	gu	mou	mou
kua	gua	mu	mu
kuai	guai	na	na
kuan	guan	nai	nai
kuang	guang	nan	nan
kuei	gui	nang	nang
kun	gun	nao	nao
kung	gong	nei	nei
kuo	guo	nên	nen
la	la	nêng	neng
lai	lai	ni	ni
lan	lan	niang	niang
lang	lang	niao	niao
lao	lao	nieh	nie
lê	le	nien	nian
lei	lei	nin	nin
lêng	leng	ning	ning
li	li	niu	nüe
lia	lia	niu	niu
liang	liang	no	nuo
liao	liao	nou	nou
lieh	lie	nu	nu
lien	lian	nuan	nuan
lin	lin	nung	nong
ling	ling	nü	nü
liu	liu	o	e, o
lo	luo, lo	ong	weng
lou	lou	ou	ou
lu	lu	pa	ba
luan	luan	pai	bai
lun	lun	pan	ban
lung	long	pang	bang
lü	lü	pao	bao
lüeh	lüe	pei	bei
ma	ma	pên	ben
mai	mai	pêng	beng
man	man	pha	pa
mang	mang	phai	pai
mao	mao	phan	pan
mei	mei	phang	pang
mên	men	phao	pao
mêng	meng	phei	pei
mi	mi	phên	pen
miao	miao	phêng	peng
mieh	mie	phi	pi
mien	mian	phiao	piao

Modified Wade-Giles	Pinyin	Modified Wade-Giles	Pinyin
phieh	pie	ta	da
phien	pian	tai	dai
phin	pin	tan	dan
phing	ping	tang	dang
pho	po	tao	dao
phou	pou	tê	de
phu	pu	tei	dei
pi	bi	tên	den
piao	biao	têng	deng
pieh	bie	tha	ta
pien	bian	thai	tai
pin	bin	than	tan
ping	bing	thang	tang
po	bo	thao	tao
pu	bu	thê	te
sa	sa	thêng	teng
sai	sai	thi	ti
san	san	thiao	tiao
sang	sang	thieh	tie
sao	sao	thien	tian
sê	se	thing	ting
sên	sen	tho	tuo
sêng	seng, sheng	thou	tou
sha	sha	thu	tu
shai	shai	thuan	tuan
shan	shan	thui	tui
shang	shang	thun	tun
shao	shao	thung	tong
shê	she	ti	di
shei	shei	tiao	diao
shên	shen	tieh	die
shêng	sheng	tien	dian
shih	shi	ting	ding
shou	shou	tiu	diu
shu	shu	to	duo
shua	shua	tou	dou
shuai	shuai	tsa	za
shuan	shuan	tsai	zai
shuang	shuang	tsan	zan
shui	shui	tsang	zang
shun	shun	tsao	zao
shuo	shuo	tsê	ze
so	suo	tsei	zei
sou	sou	tsên	zen
ssu	si	tsêng	zeng
su	su	tsha	ca
suan	suan	tshai	cai
sui	sui	tshan	can
sun	sun	tshang	cang
sung	song	tshao	cao

Modified Wade-Giles	Pinyin	Modified Wade-Giles	Pinyin
tshê	ce	wa	wa
tshên	cen	wai	wai
tshêng	ceng	wan	wan
tsho	cuo	wang	wang
tshou	cou	wei	wei
tshu	cu	wên	wen
tshuan	cuan	wêng	weng
tshui	cui	wo	wo
tshun	cun	wu	wu
tshung	cong	ya	ya
tso	zuo	yang	yang
tsou	zou	yao	yao
tsu	zu	yeh	ye
tsuan	zuan	yen	yan
tsui	zui	yin	yin
tsun	zun	ying	ying
tsung	zong	yo	yue, yo
tu	du	yu	you
tuan	duan	yung	yong
tui	dui	yü	yu
tun	dun	yüan	yuan
tung	dong	yüeh	yue
tzhu	ci	yün	yun
tzu	zi		

SUPPLEMENTARY INDEXES

For the convenience of readers, the following four supplementary indexes have been provided:

Index to Titles of Books
Includes titles, with translations, of pre-20th century Chinese books and especially important works in other languages referred to in the text, captions and footnotes, as well as abbreviations of frequently cited works.

Index of Personal Names and Organisations
Includes personal names of Chinese and non-Chinese, both historical figures and authors, that appear in the text, captions and footnotes.

Index of Place Names
Includes all place names that appear in the text, captions and footnotes. Place names in the various maps can be found in the main index, and are not repeated here. (Exception: place names from Map 10, which were inadvertently omitted from the main index, have been added to this index).

Index of Technical Terms
Includes all technical terms for which Chinese characters are provided, whether in the text, in captions, in tables or in footnotes.

Index to Titles of Books

Index of Personal Names and Organizations

Index of Place Names

Index of Technical Terms